IMPACT OF LAND TREATMENT ON THE RESTORATION OF SKINNER LAKE NOBLE COUNTY, INDIANA

By
Noble County Soil and Water Conservation District
Albion, Indiana 46701

Assisted By
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Michigan State University, ASCS, SCS

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Introduction and Summary

This document is the final report on a project designed to restore impaired uses of a freshwater, Indiana lake through watershed treatment and management. The project, designated The Skinner Lake Project, was funded by The U.S. Environmental Protection Agency, Region 5, under Sec. 104 (pollution reduction demonstrations) of the 1972 Clean Water Act. Additional funding and assistance was provided by the U.S. Department of Agriculture (Agriculture Stabilization and Conservation Service which provided funds and Soil Conservation Service which provided technical assistance), Indiana Department of Natural Resources, Noble County, Ind. Drainage Board, and private landowners. The project was administered by the Noble County Soil and Water Conservation District. Monitoring of the effect of the project on the lake was done by Michigan State University.

The project, as completed, involved two major thrusts, (1) construction and land treatment in the watershed to reduce soil erosion and the discharge of sediment and related pollutants into the lake and (2) construction of a large desilting basin on the major drain into the lake. Land treatment efforts affected 2,800 acres of the 10,000-acre Skinner Lake Watershed. As calculated according to the Universal Soil Loss Equation, an annual total of slightly more than 17,000 tons of soil loss was averted. Most of this was accomplished with three types of practices -- terraces, vegetative cover, and conservation tillage. The major desilting basin, constructed at the base of the Rimmel Drain, functioned to remove about 20 percent of the sediment entering it and accounted for a reduction in phosphorus in the lake of about 10 percent. combined, the basin and the land treatment accounted for a 13 percent reduction in phosphorus entering the lake annually which was sufficent to improve the quality of water in the lake but which was not sufficient to move the lake out of the eutrophic classification. However, the improvement was sufficient that lake treatment measures initially contemplated were not employed.

Conclusions

The following project conclusions are based on the experience gained in the land treatment portion of the project and the results of monitoring by Michigan State University:

1. Of nine types of practices which reduced soil loss during the Skinner Lake project, three --terraces, vegetative cover, and conservation tillage --resulted in almost 95 percent of the total soil saved. Although it is not possible to directly translate soil saved according to the Universal Soil Loss Equation into improved water quality, it is possible to utilize these data to draw the following conclusions:
   - (a) Since a relatively small number of types of practices proved most effective in reducing soil lost and since administration is greatly simplified when the number of practices is kept small, the efficiency of the project was enhanced by concentrating efforts on a small number of soil conservation practices.
   - (b) The effectiveness of these practices in improving the quality of water in Skinner Lake increased as the distance between the practice and a major drainage way into the Lake decreased.
   - (c) Of all practices used, conservation tillage was the most effective. The use of vegetative cover is also an effective practice.

2. Animal waste systems were effective in reducing the biological oxygen demand (BOD) of waters entering Skinner Lake. BOD was reduced annually be an amount equivalent to 154,629 pounds. This reduction may have been counterbalanced somewhat by vegetative practices which placed animals on pasture near the major drainage ways, since only one livestock exclusion was achieved.

3. Spring was demonstrated to be the critical season for nutrient loading to the lake. For the 1978-1979 period, 88 percent of the total nitrogen loading, 90 percent of the total annual phosphorus loading and 66 percent of the annual suspended particulate matter occurred in the spring. Lake sediment cores demonstrated a pattern in which stream-borne particulates settled during the spring and then were overlaid with material of littoral origin in summer, fall and winter.

4. Although the Rimmel Drain is the largest contributor of phosphorus to Skinner Lake, diversion of this drain around the lake would not benefit it since the large volume of water carried in the Rimmel contributes to the flushing of the lake.

5. If the desilting basin constructed on the Rimmel drain were 100 percent efficient, (removed 100 percent of total phosphorus) the lake would be moved from the eutrophic to the mesotrophic category, a significant improvement in water quality. If the basin removed 100 percent of the phosphorus attached to sediment, a somewhat less striking improvement in water quality would occur. These facts lead to the following conclusions:

(a) Removal of 100 percent of particulate phosphorus would have required a basin about twice as large as the one constructed. Such construction would have been more costly initially and would have involved greater annual maintenance costs. The basin would also require redesign to insure effective functioning during low-flow as well as high-flow periods. The Skinner Lake project, on balance, demonstrates the possibility of improving lake water quality by creation of artifical wetlands. However, the cost-effectiveness of this approach is less certain.

(b) A settling basin would not be expected to remove dissolved phosphorus. To remove 100 percent of the total phosphorus would require additional treatment of water entering the lake after it left the basin. This approach has not been demonstrated and may not be possible with current technology.

6. Land treatment measures are quite effective at reducing sediment, their effectiveness at removing phosphorus is less certain, but can be improved by incorporating fertilizer management into total management programs.

7. The reduction in phosphorus and sediment accomplished by the land treatment and construction phases of this project would have had little impact had not corresponding improvements in water quality been achieved through a preceding program to control septic tank effluents.

Recommendations

The Skinner Lake program was designed as a pilot program and as a model for lake restoration efforts undertaken under programs such as the Clean Lakes Program of the U.S. Environmental Protection Agency. The following are recommendations which can be of benefit to others attempting future lake restoration projects.

1. Lake restoration requires a concerted effort. Each of several measures applied in Skinner Lake had beneficial results. Combined, the efforts can be synergistic. It is recommended that coordination among agencies having different roles in lake restoration be given a high priority.

2. When the deterioration of a freshwater lake results from nonpoint source agricultural pollution, application of management practices to the land can be of significant benefit. Projects should attempt to reduce both soil loss and the amount of lost soil which actually enters the lake. One way of doing this is to preferentially apply practices which are close to the lake or to major tributaries to the lake.

3. Select practices which result in the best return in the lake watershed and concentrate on a limited number of practices which are appropriate in the particular lake watershed.

4. Cost sharing was effective in obtaining the installation of certain conservation practices, however, cost-sharing alone was not sufficient to obtain 100 percent cooperation. Other incentives should be considered on future projects.

5. The expected impact of project activities should be identified before practices are installed.

6.Adequate planning time after should be provided before construction or land treatment is begun. A good first impression is important.

7.The effectiveness of lake restoration efforts will be enhanced if the various local, state, and federal agencies which may be involved achieve maximum cooperation. A soil conservation district, which is designed to coordinate the cooperative efforts of other agencies, can often be an appropriate project administrator.

Historical Setting

The Skinner Lake project was designed to restore some of the impaired ues of Skinner Lake, a 125-acre freshwater lake located in Noble County Indiana. Skinner Lake is typical of many northern Indiana lakes.

These lakes, a legacy of the last great period of glaciation to affect Indiana, have been under pressure for more than a century. Pressures have resulted from unwise use of the lake watersheds such as intallation of improper agricultural drainage, drainage of the lakes' supporting wetlands, and from the use of the lakes for recreation and as home sites.

Summer cottages were built on many Indiana lakes by persons from urban centers such as Chicago, Fort Wayne, South Bend, and Indianapolis. An improved highway system, constructed after World War II, led to the conversion of summer homes to year around residences for many persons.

The pressure of lake and wetland drainage, coupled with the pressure of summer and year around residents, has resulted in the impaired use of many lakes, such as Skinner Lake.

Impaired Uses of Skinner Lake

The uses of Skinner Lake have been impaired by two factors, both of which have accelerated the natural process of eutrophication. The primary pollutants of this lake are sediments and nutrients. Both are contributed by improper agricultural use of the Skinner Lake watershed. Nutrients have also been historically added by sewage disposal systems for lake-front homes and cottages.

Two primary forms of lake use -- fishing and whole body contact recreation such as swimming -- have been impaired in Skinner Lake. Specifically, sediments, and attached nutrients, cause a loss of water quality and accelerate the rate at which the lake is being filled. In addition, since the growth of plant life in the lake is limited by the amount of available phosporus, phosphorus introduced to the lake causes increased algal and macrophyte growth. Die-offs of these plants deplete the amount of available oxygen in the water. The species composition of lake fish is altered so that a lower percentage of top predators, most desired by fisherman, is present. Trash fish, such as carp, become predominant.

Design of Skinner Lake Program

Prior to the Skinner Lake project, efforts to restore uses of the lake primarily attempted to treat symptoms rather than causes. These efforts included chemical killing of weeds and algae. Attempts at chemical control of weeds were largely ineffective since this practice did nothing to remove the nutrients which led to the lush weed growth in the first place.

Similarly, in 1963, an attempt to improve fishing in the lake through a total fish kill and restocking was undertaken by the Indiana Department of Natural Resources. This effort led to a temporary improvement in the fish population, but since the underlying cause of poor fishing involved the lack of oxygen in the lower levels of the lake, the lack of water clarity which interfers with the ability of sight feeding predators to control other fish populations, and the excessive weeds which also interfer with predator feeding, the improvement was short lived.

The Skinner Lake project, as initially planned, was an attempt to deal with more fundamental aspects of the degradation of the Lake. Originally, the plan was developed to include three parts:

1. Continuing control of the nutrient outputs of septic tanks. Prior to the development of the project, a program to control septic tank effluent into the lake had been undertaken by the Noble County Board of Health.

2. Control of sediments and related pollutants from agricultural operations. This involved an extensive plan for land treatment which is detailed later in this report.

3. Removal and/or inactivation of nutrients which have built up in the lake. This latter phase was abandoned, as a result of the success of the first two phases.

The project was initiated through

the efforts of former Rep. J. Edward Roush and the Noble County Soil and Water Conservation District. The district's board of supervisors, with help from the Soil Conservation Service, submitted a proposal to restore Skinner Lake to the U.S. Enviornmental Protection Agency. In January 1977, a grant of $403,249 was awarded the district on a 50-50 matching basis for a total project budget of $806,501. An additional $100,000 was awarded in July 1980 bringing the total project budget to $1,006,501 and extending the completion of the project to December 1982. Of the original funds, $60,748 was budgeted for weed control and chemical treatment if these projects should be deemed necessary.

Physical Setting

Skinner lake is a natural, glacial lake located at the base of an agricultural watershed. The watershed area is about 80 times the area of the lake itself. This section sets forth some of the details about the lake and its watershed.

Skinner Lake

Skinner Lake has a surface area of 125 acres, a volume of 570 million gallons, a maximum depth of 32 feet, and an average depth of 14 feet. The lake basin is shaped very much like a hat with a shallow ledge surrounding a deep basin. Most of the ledge produces abundant weed growth in the summer months. Public access to the lake is obtained from Indiana highway 8, an east-west state operated and maintained roadway. The major public recreational use of the lake is fishing.

Approximately 125 cottages and homes are located on Skinner Lake. Sewage disposal for these homes, most of which are permanent, year-around residences, is by septic tanks. Until 1975, there was significant flow from these septic tanks into the lake. In the summer of 1974, the Noble County Department of Health began a testing program which led to redesign of inadequately functioning septic systems. This program halted the flow of septic tank effluent directly into the lake. Although even upgraded septic systems can contribute to the flow of nutrients into the lake, it appears likely that because of the predominant soil types, the size of the watershed, and the flushing of the lake, this represents a minor portion of the total nutrient budget.

Skinner Lake Watershed

Skinner Lake is located at the bottom of a 9,977-acre watershed which is primarily devoted to agriculture. At the beginning of the project, the watershed contained 7,680 acres of cropland, 889 acres of woodland, and 1,408 acres of other land including idle land, wetland, homes and roads. The watershed is pictured in figure 1. There are 76 different types of soil in the watershed. These can be grouped into 34 separate land capability units.

The primary agricultural land use is for cash grain production, chiefly corn and soybeans. Both of these crops require the application of nitrogen and phosphorus fertilizers, some of which find their way into the lake as a result of leaching or erosion. Farmers typically apply an average of 125 pounds of nitrogen per acre per growing season. Phosphorus

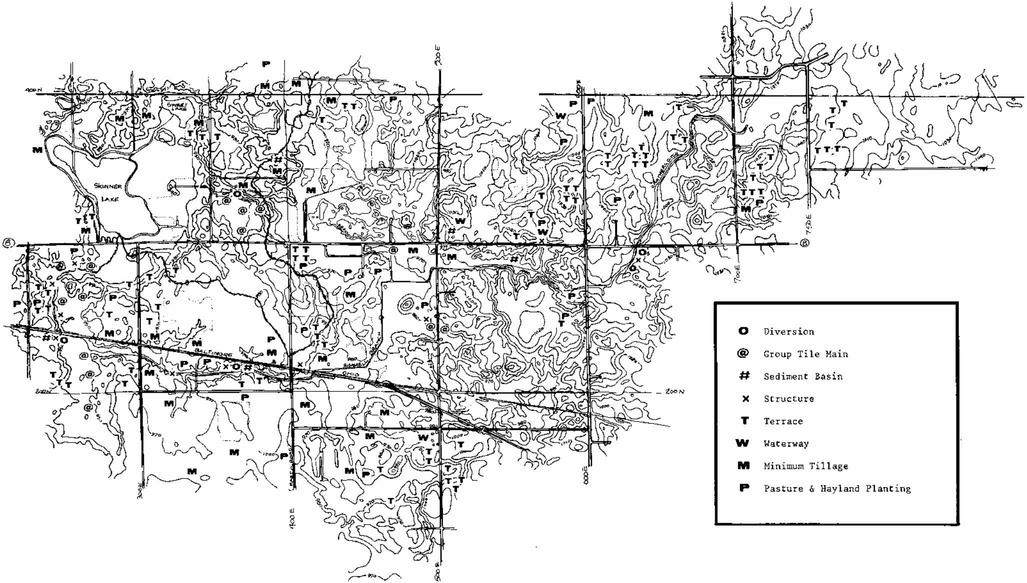


Figure 1: Skinner Lake Watershed With Land Treatment Indicated

is applied at a rate of 50 pounds per acre as phosphates. Potash application is typically 150 pounds per acre.

Water from the agricultural watershed enters Skinner Lake through three major drains. Of these, the Rimmel Drain is the largest. It combines drainage water from 5,000 acres of the watershed. Other drainage enters the lake from the North with an open stream beginning at a smaller, highly eutrophic lake, Sweet Lake, and through an agricultural tile, designated the Hardendorff Drain. The open drainage from Sweet Lake is through a wetland area and a heavily wooded area. The Hardendorff Drain has its outlet at the lake surface.

Administrative Setting

The Skinner Lake project was designed to be administered by the Board of Supervisors of the Noble County Soil and Water Conservation District. This sections describes the basic administrative philosophy, outlines project organization, and lists key project personnel.

Administrative Philosophy

The planning for the Skinner Lake project was based on the belief that land use changes, erosion control, management practices, and other treatment measures will provide, over the long-term, the most enduring conservation benefits for the restoration of the lake. In order to accomplish the needed changes, the project administration relied on a voluntary program, and insisted that the voluntary character of the program be continuosly emphasized, although the participation of individual landowners was actively sought.

As an incentive to landowners to participate in the program, the project offered cost sharing. Through cooperative federal funding with EPA and ASCS funds, cost share on an individual practice could be as high as 85 percent.

In order for a landowner to participate in the program, a plan of operations, including a time schedule, was required. The cooperating landowner was responsible for developing and carrying out the plan of operations. However, the district was able to provide technical assistance through the Soil Conservation Service.

Based on a developed plan of operations, the district was able to enter a long-term contract which committed the district to share in the cost of establishing certain conservation practices.

Project Organization

Ultimate local responsibility for the Skinner Lake project was vested in the SWCD board of supervisors. This board is made up of five members, two of which are appointed by the state soil and water conservation committee on recommendation of the local board and three of which are elected by the landowners of the county. Project activities were reviewed by the board at its regular monthly meetings. The chairman of the board was designated the project administrator

In this capacity, he served as chairman of an advisory committee, created in an attempt to obtain public input toward the project. The advisory committee was established to include three representatives selected by the residents of property adjoining the lake, three representatives selected in the balance of the watershed, a representative of the Cooperative Extension Service.

Serving under the board of supervisors was a project manager. The manager was responsible for day to day supervison of the project including handling of contracts, training of district employees, and conducting an information program.

The Soil Conservation Service, through its area offices and through additional personnel, paid in part by project funds, provided technical assistance.

Key Project Personnel

The following are key personnel who served on the project:

Soil and Water Conservation District — chairmen, Hugh Sherwin, Jack Wolfe. Members, Elbert Roe, Max E. Hill, Emmert Herr, Wayne Clouse, Fred L. Geiger, Galen Swogger, John McClanahan. Project Managers, Austin W. Fergusson, Jack Chronister. Other employees, Carolyn Adair, Evelyn Morr, Susan Londt.

Local SCS Personnel — District Conservationist, Carl S. Diehl. Other personnel, Randy Moore, Barry Bortner, Sam St. Clair, Mark Depoy.

Area SCS Personnel — Fremont Schoeck, Bud Poland, Lowell Hunter.

USEPA project Officers —Wayne Gorski, Don Roberts.

Michigan State University — C.D. McNabb, B.J. Premo, J.R. Craig, M. Siami, B. Glenn.

Planning and Accomplishments
Land Treatment

The Skinner Lake program for land treatment was based on the administrative philosophy previously described. Implementation was based on education of farmers to the problem that particular farming operations may present to the lake and the offering of incentives, in the form of cost sharing, to apply needed practices which will reduce the amounts of sediments and related nutrients leaving their farms to enter the drainage streams. Particular effort was made to get conservation practices applied on the land immediately adjacent to the lake area or lake tributaries.

Cost share incentives were offered to individuals and groups for the following practices outlined in the original plan of work — minimum tillage, critical vegetative protection, diversions, grade stabilizations, grassed waterways, terraces, livestock exclusion, tree planting, tile main, vegetative cover— and for three additional practices for stream bank protection, animal waste management, and sediment control basins. All practices came from the Soil Conservation Service Technical Guide.

The amount of cost sharing offered was based on the lesser of the SCS engineer's estimate or submnitted paid invoices. The board of supervisors decided not to vary the rate of cost sharing for the duration of the project in order to provide equality among landowners and to encourage prompt signing of contracts rather than waiting for the rate to increase. Cost-share procedures were similar to those employed by ASCS under ACP, except that no hold-down provisions were put in effect. Farmers were comfortable with these procedures. Many had previous experience with ACP programs.

Under the Skinner Lake Project, any

person who had control of an operating unit of land in the Skinner Lake area was eligible for participation. To participate, the person was required to sign an application to become a cooperator with the Noble County Soil and Water Conservation District. The priority for applications was based on a first come first served procedure. Each application was dated. The SWCD board of supervisors retained the ability to accept or reject applications under the established guidelines of the Indiana Soil and Water Conservation Districts.

In determining whether to accept or reject an application, the board referred to the following factors:

1. The work plan and objectives of the project.

2. The seriousness of the soil and water conservation problem, including its relationship to sediment and agriculturally related pollution.

3. The need for simultaneous action by two or more cooperators in controlling erosion -- a group of cooperators, each an individual application, agreeing to coordinated action in meeting erosion problems would ordinarily be prefered over an individual applicant.

4. Urgency for the application of the conservation measures.

5. Time of filing of the application in relation to other applicants.

6. Interest and attitude of the applicant and his understanding of the project.

To participate, the cooperator was required to develop a conservation plan with the aid of the SCS. The SCS resource conservation planning hanbook and technical guide was used to establish the minimum requirements for the conservation plan. The conservation plan could use any appropriate conservation practice, whether or not it was eligible for cost share under the project or required in the plan of operations (described below). Conservation plans were subject to approval of the SCS district conservationist.

From the items in the conservation plan, the cooperator was responsibile for developing a plan of operations with the assistance of the SCS and the district. The plan included all items of soil and water conservation to be accomplished during ensuing three-year, project span. (The orginal project period was Januar 1, 1977 through December 31, 1980. It was later extended to Septeber 18, 1981 and then to December 31, 1982.) The plan of operations was made a part of a contract between the cooperator and the district. Two plans for implementing contracts were considered by the board. Elements of the plan accepted for group and individual contracts is outlined below.

Procedure for Group Contracts

The following was the published procedure for group contracts under the project:

1. The individuals in the group will sign up as cooperators with the Noble County Soil and Water Conservation District. This basic agreement allows the district representatives to provide assistance.

2. The district and the Soil Conservation Service will assist the individuals and groups in developing a conservation plan which will identify all conservation practices needed on their lands.

3. Out of the conservation plan will be developed a plan of operations which will be valid from March

18, 1977 to March 18, 1980.

4. On the basis of the plans of operation, the District will enter into a contract with the individual and/or group to provide cost share assistance for the application of water quality conservation practices on their lands. The conservation practices will be outlined in the contract giving the estimated cost sharing amount to be provided by the District in the year the practice will be installed. Cost share amounts will be based on the percentage determined by the district from funds available from the U.S. Environmental Protection Agency.

5. A bidding procedure will be used. The procedure to be followed will be as specified in 40 CFR Part 33-Subagreements, Subpart D-Procurement by Formal Advertising. A Soil Conservation Service engineer will develop the plans and specifications and completion schedule for the work to be performed for the group to advertise for a contractor. The design will be developed from field surveysys and engineering design criteria established by the Soil Conservation Service and approved by the U.S. Environmental Protection Agency's project officer, before contractors are notified of the bid opening date. 6. A listing of responsible bidders, prepared by the Noble County Soil and Water Conservation District and the Soil Conservation Service will be provided.

7. An appropriate Soil Conservation Service official will be placed in charge of supervising the installation of all recognized conservation practices in the contract.

8 Where a contractor is used other than an individual farmer on his land, paid invoices shall be submitted in order to receive cost share payments.

9. Cost share rates will be applied to the lesser of the Soil Conservation Service engineer's estimate of Soil Conservation Service established rate per unit, or submitted paid invoices.

10. Each conservation practice where cost share amounts are available will be considered a contract and must be certified by the appropriate Soil Conservation official before payment can be authorized. Authorization for payment will be by a properly executed claim form by the Board of Supervisors who will have in hand properly executed application for payment, certification, and report of in-kind matching contributions.

Individual contracts

When the contract was between an individual and the district, the basic parts of this procedure were applied with the exception that for individuals, bidding was only required when the cost was equal to or greater than $10,000.

Establishing Cost Share Rates

The original cost share rates established by the board of supervisors were based on the terms of the project which called for 50 percent federal and 50 percent local funding. Rates established included: sediment basins, 50%; minimum tillage,35%; critical area vegetative protection, 35%; diversions, 35%; erosion control structures, 40%; grass waterways, 45%; terraces, 45%; livestock exclusion, 35%; tree planting, 40%; tile mains, 25%; vegetative cover, 40%; open ditch, 40%; animal waste systems, 30%; and maintenance, 100%.

The board determined that cooperators would not be allowed to pick out the high percentage items if other items, of lower cost-share rates, were also needed.

In setting the rates the board considered (1) the likely effectiveness of the practice in achieving the goals of the project; (2) benefits received by the farmer; (3) the amount of cost share necessary to obtain voluntary participation; (4) Payments offered in the Black Creek Project and under regular ASCS programs; (5) recommendations from the project manager and SCS; (6) the need to devote some project funds to administration.

Cost share rates were a factor in the adoption of the practices, and in fact, the original rates were not high enough to attract much interest among landowners. When Cooperative Federal Funding was applied to the project, cost share rates effectively became 80 to 85 percent of total cost. As the project progressed into its final years, interest among landowners increased. When the project was closed, some farmers expressed a desire to apply for funds after they had observed the success of the practices on neighbor's farms.

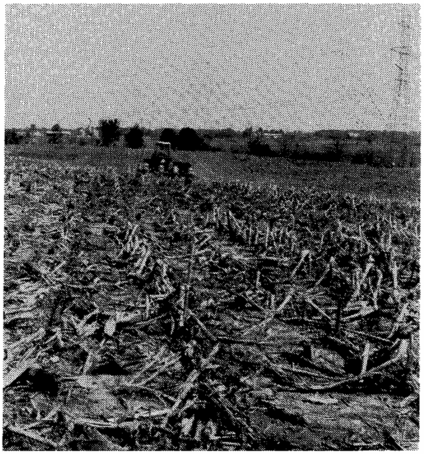
Planned and Applied Land Treatment

The plan to treat the watershed was developed based on estimates of the amounts of various practices which could be applied in the watershed. This planning process did not involve a site by site analysis of specific practices to be applied, but rather a general cataloging of the types of practices which could be applied to solve specific water quality problems. Thus it was an estimate of the amounts and kinds of practices which could be applied in the Skinner Lake Watershed to achieve soil conservation treatment.

The following discussion describes the various practices, sets forth the amounts it was assumed could be applied to obtain total treatment of the watershed, and then sets forth the amounts which actually were applied along with an evaluation of the success of the various practices.

<u>Minimum tillage</u>. This practice was defined to be any form of tillage which reduces the number of agricultural operations performed in connection with the production of row crops. The practice controls erosion by an increase in surface roughness and an increase in the amount of residue left on the soil surface. The residue decreases the amount of soil detachment associated with raindrop impact, and both the residue and the increased roughness can impede overland flow and help increase infiltration. Reduction in tillage thus not only decreases erosion but decreases the amount of phosphorus leaving the land. In the Skinner Lake Watershed, 5850 acres were considered suitable for minimum or conservation tillage. The project achieved 20 percent of this amount, but judged conservation tillage to be the most successful practice in the project. According to Universal Soil Loss Equation estimates, 7,141 tons of soil were saved annually by the practice. That the project had an impact on the rate of adoption of the practice is demonstrated by the fact that in the balance of the county, only 8 percent of the possible land available for conservation tillage is so used.

<u>Critical vegetative protection</u>. This practice involves the establishment of permanent vegetative cover in critical areas. Included would be such practices as field borders and stream bank plantings. The practice



Minimum Tillage

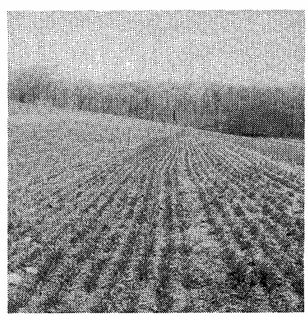
did not prove to be popular in the Skinner Lake area. Of a possible 35 acres of critical area plantings, only .75 acre was achieved.

Diversions. Diversions are structures which direct the flow of surface water from areas where its concentration would be damaging to areas where the water can be more easily managed. In some cases, a terrace system can be subsituted for a diversion, and this appears to have happened frequently in the Skinner Lake Project area. Planners indicated that 40,000 feet of diversions could be constructed in the watershed. In fact, only 2,700 feet or about 7 percent of the possible amount, was constructed.

Grade Stabilization. Grade stabilization is usually obtained by the construction of a structure to lower flowing water over a sharp elevation in such a way as to prevent channel erosion. Planners saw the possibility of installing 105 structures in the watershed. Of these, only 12 were installed. Most of the structures which were constructed were in the lake's major tributary, the Rimmell Drain. Planners of the project hoped for participation of the Noble County Drainage Board in controlling the flow of the Rimmel Drain, and thus planned for a large number of stabilization structures. This participation did not materialize. Among structures which were built was included barriers in the Rimmel Channel, rip-rap bank protection, and bank stabilization.

Terraces. These were among the most popular practices in the project. Of the 50,000 feet considered possible, more than 43,000 feet were constructed. Terraces cause retention of surface water on the land and meter its flow into a receiving stream, as a result, both soil and related nutrients are retained on the land. Studies of terrace systems as a part of the Black Creek project have indicated that this practice can reduce the amount of sediment and sediment-bound phosphorus entering the drainage stream by as much as 90 percent. By Universal Soil Loss Equation estimates, terraces in the watershed saved 5,941 tons of soil annually, making the practice the second most important in terms of erosion reduction for the project.

Livestock exclusion. This practice is important for protection of streams both from livestock damage and from livestock waste. Planners

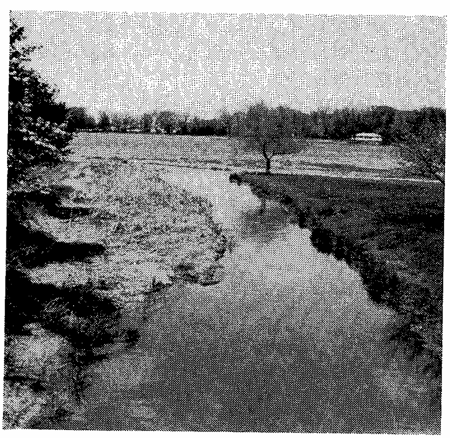


Cropland and Terrace

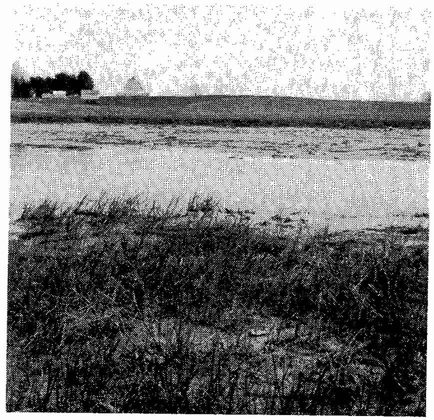
estimated that 3,000 rods of livestock exclusion could be constructed in the Skinner Lake watershed. However, only one landowner elected to participate in this practice.

Tree Planting. Of the 100 possible acres for tree planting, only 7.75 acres were actually planted to trees as a part of the project. However, tree planting on less than two acres achieved a reduction in soil loss of more than 50 tons per year. The practice was cheap and effective

Tile. Only 4,686 of a possible 50,000 feet of tile main was installed as a part of the project. In the project, the practice was limited to tile lines which inolved two or more land owners. It was targeted at failed drains into which uncontrolled surface water was discharged. Five small systems were installed. Generally, the outlet tile for group terraces replaced broken tile lines. The effectiveness of these projects is indicated by the fact that sand bars which typically built up below discharge points for at least two of the group terrace projects have not returned.



Sediment in Lake



Large Sediment Basin

Other practices. Sediment basins were constructed at three locations, resulting in an annual estimate of soil saved of 590 tons. Although these practices are expensive, they represent an effective measure for protection of critical erosion areas. Vegetative cover, largely in the form of cover crop, pasture, and hayland planting, was installed on 511 acres of the watershed. The practice resulted in an annual reduction of soil loss of 3,025 tons. Fifteen of the fields so treated are on slopes fronting the Rimmell Ditch. The practice was considered highly effective, but vulnerable to the plow. It was little used by grain farmers, being more adapted to farms involved in the production of animals.

Banks of open ditches were resloped and seeded as a part of the construction portion of the project to be discussed later. The reconstruction of open drains was surpervised by the Noble County Drainage Board which also participated financially. In the Rimmell Ditch, severe side slope slippage and bank erosion from the lake to the area of Noble County Road 400 East was occurring as a result of earlier reconstruction efforts. Deltic deposits at the lake were observed to contain stumps, railroad ties, gravel and small chunks of clayey material, presumably from slipped banks. Sloping and seeding has effectively controlled this source of sediment and debris. Although there are few feed lot and dairy operations in the watershed, cost sharing on certain animal waste projects was considered desirable. Work on three waste management projects resulted in an annual reduction in the Biological Oxygen Demand equivalent to 154,629 pounds. Cost sharing on animal waste system was, however, limited to an amount not to exceed the cost-share obtained for conservation practices by the landowner.

Summary

The following table provides a summary of the land treatment practices installed, the unit cost and the total cost for the project.

LAND TREATMENT SUMMARY

Practice	# of Applications	Units Built	Unit Cost	Total Spent
Minimum Tillage	17	1,276 A	10.49	12,371.00
Critical Vegetative Protection	1	3/4 A	548.00	411.00
Diversion	5	2,700 FT	.66	1,792.00
Grade Stabilization Structure	9	12	573.89	6,886.00
Terraces	22	43,405 FT	5.71	246,840.00
Livestock Exclusion	1	26 RODS	11.44	305.00
Tree Planting	4	7.75 A	70.60	547.00
Tile Main	5	4686 FT	1.17	4,278.00
Vegetative Cover	22	511 A	25.04	12,980.00
Animal Waste System	3	3	4,170.00	12,509.00
Small Basin	3	3	4,544.00	13,633.00

The following tables summarize the installation of land treatment measures on a site by site and practice by practice basis.

Prior to the beginning of the project, conservation practices in the area included crop rotations, hayland, a few diversions, and considerable amounts of field tile. At the time the project was begun, many farmers had abandoned some conservation practices in order to intensify grain farming. In most cases, these landowners recognized the need for soil erosion control, but found traditional practices for accomplishing this goal unattractive or uneconomical.

The project provided watershed farmers conservation tools, some of which do not interfer with grain farming. A few practices — construction of parallel terraces, establishment of vegetative cover, and conservation tillage — proved most effective at controlling erosion. These practices saved 16,107 tons of soil out of the 17,015 saved annually by all practices undertaken. Of these practices two — terraces and conservation tillage, are consistent with intensive farming.

In order to obtain the maximum impact on the lake, conservation efforts were concentrated on critical sites, particularly those with slopes fronting the lake or its tributaries.

Animal waste systems were needed on very few farms. Cost-sharing for animal waste control was limited.

INDIVIDUAL SITE HISTORY

Practice: Sediment Basins

Name	Purpose	Amount (number)	Status	Evaluation
Detwiler	Site fronts ditch	1	OP	92 TSS A
Hass	Needed to stop overland flow to Halferty ditch	1	OP	328 TSS A
A. Reeve	Prevent sediment from reaching failed tile	1	OP	170 TSS A

Practice: Diversion

Name	Purpose	Amount (feet)	Status	Evaluation
Heileman	Adjacent to Rimmell Ditch	650	OP	10 TSS A
L. Moening	Control sediment to Rimmell Ditch	200	OP	2 TSS B
L. Ober	Redirect water from contaminating source	325	OP	2 TSS C
W. Stroup	Stop ditch bank erosion on Rimmell Ditch	800	OP	4 TSS A
F. Winebrenner	Reduce sediment movement to Rimmell Ditch	725	OP	7 TSS B

Notes: OP=operational, DIS= Discontinued; S = replaced by seeding. TSS= tons of soil saved annually. A, B, C indicate proximity to water with A being closest.

INDIVIDUAL SITE HISTORY

Practice: Conservation Tillage

Name	Purpose	Amount (acres)	Status	Evaluation
Allgood	Sediment source near water	88	DIS	241 TSS A
E. Bauman	Adjacent to Rimmell Ditch	30	OP	240 TSS A
DePew	Adjacent to Rimmell Ditch	28.2	OP	110 TSS A
Diehl	Promote no-till	4	OP	17 TSS C
D. Gorsuch	Erosion control critical slope above Rimmell Ditch	18	OP	54 TSS A
Hague	Adjacent to Rimmell Ditch	38	S	41 TSS B
Hass	Some slopes face Haferty Ditch	217.3	OP	1050 TSS A
Higginbotham	Adjacent to Rimmell Drain	47	OP	249 TSS A
Jacobs	Reduce sediment at Clapp outfall	70	OP	182 TSS C
H. Knafel	Slopes face Rimmell Ditch	58	OP	183 TSS A
J. Knafel	Slope to Parker Branch	117	OP	516 TSS A
L. Ober	Slope above terrace in Hardendorff system	6	DIS	32 TSS C

Notes: OP=operational, DIS= Discontinued; S = replaced by seeding. TSS= tons of soil saved annually. A, B, C indicate proximity to water with A being closest.

INDIVIDUAL SITE HISTORY

Practice: Conservation Tillage (continued)

Name	Purpose	Amount (acres)	Status	Evaluation
R. Sieber	Slopes front Skinner Lake	113.4	DIS	1670 TSS A
J. Sieber	Within Harden-dorff system and above terrace	286	OP	2202 TSS B
B. Smurr	Erosion control	15	OP	303 TSS B
R. Stoneburner	Fronts Skinner Lake	30		
W. Stroup	Erosion control adjacent to Rimmell Ditch	13	OP	47 TSS A

Practice: Animal Waste System

Name	Purpose	Amount (number)	Status	Evaluation
Allgood	Control feedlot runoff to Rimmell	1	OP	62962 Lbs BOD reduction A
Depew	Control feedlot runoff to Rimmell	1	OP	61679 Lbs BOD reduction A
Hague	Control feedlot runoff to Rimmell	1	OP	29988 Lbs BOD reduction A

Practice: Critical Vegetative Protection

Name	Purpose	Amount (acres)	Status	Evaluation
Hague	Adjacent to Rimmell Ditch	.75	OP	1.7 TSS A

Notes: OP=operational, DIS= Discontinued; S = replaced by seeding. TSS= tons of soil saved annually. A, B, C indicate proximity to water with A being closest.

INDIVIDUAL SITE HISTORY

Practice: Structure

Name	Purpose	Amount (number)	Status	Evaluation
Allgood	Sediment retention on critical site Rimmell Drain	1	OP	10 TSS A
Gorsuch	Sediment retention on critical site Rimmell Drain	2	OP	60 TSS A
Heileman	Control ditch bank erosion on Rimmell Drain	1	OP	10 TSS A
J. Knafel	Stabilize scour point in Parker Branch	1	OP	10 TSS A
N. Mantel	Stop ditch bank erosion in lateral to Rimmell Ditch	1	OP	10 TSS A
L. Moening	Sediment retention in gully above Rimmell Ditch	1	OP	75 TSS A
W. Stroup	Control bank erosion on Rimmell Ditch	2	OP	20 TSS A
R. Rohyans	Control ditch bank erosion on Rimmell	2	OP	20 TSS A

Notes: OP=operational, DIS= Discontinued; S = replaced by seeding. TSS= tons of soil saved annually. A, B, C indicate proximity to water with A being closest.

INDIVIDUAL SITE HISTORY

Practice:Structures (continued)

Name	Purpose	Amount (number)	Status	Evaluation
F. Winebrenner	Safely outlet diversion	1	OP	10 TSS A

Practice: Terraces

Name	Purpose	Amount	Status (feet)	Evaluation
Becker	Control hill slope erosion	2200	OP	166 TSS C
E. Bauman	Control hill slope erosion	950	OP	175 TSS A
DePew	Control sedim from slope facing Rimmell Drain	2575	OP	112 TSS A
Freeman	Control sediment entering Halferty	1530	OP	78 TSS B
Garrison	Control erosion above Skinner Lake	300	OP	15 TSS B
Gorsuch	Sediment retention on critical slope facing Rimmell Drain	600	OP	44 TSS A
Hague	Sediment retention on critical slope facing Rimmell Drain	2050	OP	46 TSS A
Hass	Critical hill slope erosion in Riddle Branch	4050	OP	548 TSS A

Notes: OP=operational, DIS= Discontinued; S = replaced by seeding. TSS= tons of soil saved annually. A, B, C indicate proximity to water with A being closest.

INDIVIDUAL SITE HISTORY

Practice: Terraces (Continued)

Name	Purpose	Amount (feet)	Status	Evaluation
H. Mantel	Control hill slope erosion	575	OP	60 TSS C
L. Ober	Control hill slope on Harden-dorff system	1330	OP	136 TSS C
J. Sieber	Control hill slope erosion on Hardendorff	850	OP	165 TSS C
B. Smurr	Control hill slope erosion on Hardendorff	1340	OP	262 TSS C
W. Stroup	Sediment reten-tion on critical slope on Rimmell	1200	OP	11 TSS A
R. Stoneburner	Sediment reten-tion adjacent to lake	900	OP	139 TSS A
R. Rohyans	Sediment reten-tion on critical slope near Rimmell	475	OP	55 TSS A
L. Slain	Sediment reten-tion on critical slope near Rimmell	800	OP	48 TSS A
F. Winebrenner	Sediment reten-tion on critical slope near Rimmell	800	OP	104 TSS A

Notes: OP=operational, DIS= Discontinued; S = replaced by seeding. TSS= tons of soil saved annually. A, B, C indicate proximity to water with A being closest.

INDIVIDUAL SITE HISTORY

Practice: Vegetative Cover

Name	Purpose	Amount (acres)	Status	Evaluation
Aldred	Near Rimmell	14 15	DIS OP	28 TSS 28 TSS B
Allgood	Reduce erosion in Halferty Ditch	22		292 TSS B
A. Bauman	Agronomic erosion control in Bauman Group	24	OP	155 TSS A
E. Bauman	Agronomic erosion control in Bauman Group	42	OP	303 TSS A
Benton	Agronomic erosion control adjacent to Rimmell Ditch	16	OP	241 TSS A
Bortner	Agronomic erosion control near Rimmell Ditch	6	OP	73 TSS A
Freeman	Agronomic erosion in Riddle System	4	OP	92 TSS B
Gorsuch	Agronomic erosion of critical slope near Rimmell	32	OP	193 TSS A
Hague	Agronomic erosion control on critical slope near Rimmell	35	OP	156 TSS A

Notes: OP=operational, DIS= Discontinued; S = replaced by seeding. TSS= tons of soil saved annually. A, B, C indicate proximity to water with A being closest.

INDIVIDUAL SITE HISTORY

Practice:

Name	Purpose	Amount (acres)	Status	Evaluation
Higginbotham	Agronomic erosion adjacent to Rimmell Drain	25	OP	60 TSS A
Hovarter	Agronomic erosion control in Bauman Group	29	OP	142 TSS B
Hullinger	Agronomic erosion control on critical slope above Rimmell	9	OP	37 TSS B
N. Klopfesnstein	Agronomic erosion control agjacent to Rimmell Drain	55	OP	367 TSS A
J. Knafel	Agronomic erosion control adjacent to Rimmell	10	OP	65 TSS A
W. McQuire	Agronomic erosion control	14	DIS	136 TSS C
Middleton	Agronomic erosion control	15	OP	15 TSS A
Moening	Agronomic erosion control near Rimmell	9	DIS	54 TSS A
Ober	Agronomic erosion control in Hardendorff	28	OP	78 TSS C

Notes: OP=operational, DIS= Discontinued; S = replaced by seeding. TSS= tons of soil saved annually. A, B, C indicate proximity to water with A being closest.

INDIVIDUAL SITE HISTORY

Practice: Vegetative Cover (continued)

Name	Purpose	Amount (acres)	Status	Evaluation
J. Sieber	Agronomic erosion control in Hardendorff	13	OP	198 TSS C
R. Sieber	Agronomic erosion control in Hardendorff	5	OP	B
B. Smurr	Agronomic erosion control above Rimmell	47	OP	537 TSS B

Practice: Tile

Name	Purpose	Amount (Feet)	Status	Evaluation
Bortner Pulver Hullinger	Replace failed tile-terrace outlet-Rimmell	1612	OP	A
Mantel Rimmell	Replace failed tile outfall	1261	OP	C
Klopfenstein Allgood	Replace over-land flow to Halferty Ditch	526	OP	C
Bortner Diehl	Replace failed tile	236	OP	C

Notes: OP=operational, DIS= Discontinued; S = replaced by seeding. TSS= tons of soil saved annually. A, B, C indicate proximity to water with A being closest.

Planning and Application
Construction

The bulk of construction work involved two of the major tributaries to Skinner Lake, the Rimmell and Hardendorff Drains. Of these, the most extensive involved the Rimmel System, a situation dictated by the fact that the Rimmell system provides 79 percent of the water discharged to the lake. Work on the Rimmell Drain was divided into into three parts — the Rimmell Basin, Rimmell Channel, and Lower Rimmell Drain.

Lower Rimmell Drain Work on the lower Rimmell Drain was undertaken by the Noble County Drainage Board. It largely involved removal of a sandbar from the lake and some repair of the lower channel. The work area was from the site of the sediment basin to the lake. The sandbar had developed following a reconstruction and cleaning of the Rimmell Drain by the drainage board prior to the beginning of the Skinner Lake Project. Cost of work on the lower Rimmell Drain was slightly more than $32,000.

Rimmell Channel. Work on the Rimmell channel above the sediment basin was undertaken as a cost sharing project between the drainage board and the project. The work was not a drainage effort but involved repair of the ditch which had been reconstructed before the project began. The work, which cost slightly more than $40,000 involved bank stabilization, bank seeding, and resloping of banks to the natural angle of repose (2 to 1 side slopes).

In addition to this work seven structures were constructed to protect overflow areas. Stone barriers intended to armour side slopes against scour action during high flow were installed. Three areas of stone chutes were built to reduce grade and slow flow.

Due to weather conditions, the first atempt to reseed the banks was unsuccessful. As a result, hydroseeding was used during 1981 to complete the repair.

Prior to the maintenance of the lower Rimmell channel and reconstruction of the banks and addition of strutures on the Rimmell channel large quantities of silt were washed down the stream into the lake, producing the type of sand deposit described above. The completed work on the drain seems to have eliminated many of these problems.

Rimmell Basin. The basin is a rectangular constructed marsh located about 800 feet up the Rimmell channel from Skinner lake. It was constructed at a cost of slightly more than $40,000 from project funds administered by the district board. Because of a misunderstanding about the nature of work to be accomplished by the original contractor on the basin, a second contractor was hired to move some earth to an area which was to be filled. After the basin was completed, a 100-year frequency rain occurred, producing some damage to the basin and requiring repair by yet a third contractor. Future maintenance, to include repair and cleaning as necessary, was assumed by the Noble County Drainage Board.

Operation of the basin is as follows: At low discharge, water in the Rimmell is directed via a southern border channel toward the southeast corner of the basin. There the channel opens into the basin. The water flows downslope toward the northeast corner of the basin and then toward the northwest corner where it leaves the basin in a channel to the lake. At high storm discharge, during snowmelt and spring floods, the channel of the south border overflows its level and spills onto the basin. During low flow, water tends to follow a channel through the basin rather than being directed over its planned route.

The Rimmell basin provides about five acres of surface area for water detention and settling. This is roughly half the amount of area calculated necessary to provide 100 percent removal of particulate matter from the flowing water. However, despite these problems, the basin has proved to be effective in reducing the amount of sediment and phosphorus entering the lake. Monitoring estimates indicate reduction of sediment by 18 percent and of phosphorus by 10 percent

Hardendorff Drain

Two alternatives were considered for construction on the Hardendorff Drain. The first proposal, eventually rejected, involved diversion of the Hardendorff drainage water around the lake into the Croft Drain and ultimately into the Elkhart River.

The second alternative was was selected because a diversion would have added $19,000 to the cost of the project. A sediment basin, 100 feet long, was installed between the Hardendorff main and the lake to serve as a silt trap. The basin was dug before intallation of the main and cleaned after installation. Another part of the plan was to eliminate a drop in the existing tile line so as to decrease the grade from .25 feet per hundred feet to .15 feet per hundred feet. This increased the fall, as would the rerouting option. However, it required the construction of 100 feet of open channel. The channel was designed to serve as a sediment basin, In all 4,500 feet of channel was reconstructed at a cost of slightly more than $37,000. The project shared the cost with the drainage board.

The original estimated cost of the Hardendoff tile main was $16,000. The board thus agreed to pay $8,000 of the project with the drainage board to pay the balance.

Direct Treatment of Skinner Lake

Original plans for the Skinner Lake project included the possibility of lake treatment to further improve the trophic state of the lake. Outlined plans included two possible treatments: (1) mechanical harvesting and on-land disposal of weeds as a possible method of nutrient removal, and (2) chemical treatment of the lake with aluminum sulfate in order to tie up phosphorus present as phosphate in bottom sediments.

Direct lake treatment plans were eventually abandoned, largely on the advice of project investigators from Michigan State who indicated that these practices were not likely to improve the trophic state of the lake.

Citizens Advisory Committee

The citizens advisory committee was created to assist the Soil and Water Conservation District in obtaining public input toward the project objectives and accomplishments. The committee was composed of three representatives selected by residents of lake property, three representatives selected by property owners in the balance of the watershed, a representative of the Cooperative Extension Service, a representative of the Noble County Drainage Board, and a representative of the SWCD who served as chairman of the committee.

The advisory committee met rather frequently during the first year of the project;however, meetings became less frequent as the project progressed. No meetings were held with the board during the final year of the project.

The advisory committee did furnish boats and other assistance to investigators on the project.

It is the opinion of the SWCD supervisors that greater involvement by the advisory committee could have resulted in greater public understanding and input into the project. It was noted, however, that more participation by the advisory committee would have been anticipated if the project had moved forward to the lake treatment phase of the project.

Monitoring Results

A team of investigators from Michigan State University, studied Skinner Lake during the land treatment and construction project in an attempt to evaluate the success of the project in reducing the trophic state of Skinner Lake. A discussion of their results is included in a project report, "A Cooperative Project to Determine the Effectiveness of Land Treatment in Reducing the Trophic State of Skinner Lake, Indiana," by C.D. McNabb, B.J. Premo, J.R. Craig, and M. Siami, Department of Fisheries and Wildlife, Michigan State University.

A summary of the results of their investigations is presented here. The full report is included as an Appendix.

The evaluation of Skinner Lake was made by evaluation of the fit of Skinner Lake to the Vollenweider and Kerekes lake phosphorus model. This model utilizes phosphorus loading to determine the trophic state of the lake. A eutropic lake is highly productive, nutrient laden, and in decline. An oligotrophic lake would be relatively non-productive. In general, movement on the trophic scale from eutrophic toward oligotrophic is considered an improvement in lake quality.

Utilizing the model, the investigators attempted to predict which management strategies would most reduce the trophic state of the lake. The investigators then used the model to evaluate the success of the implemented land management practices in reducing the trophic state of the lake.

Data collected during the pretreatment phase show a good fit of the lake to the model. The following observations can be made concerning the lake:

1. Because the lake is small, flushing coefficients of the lake are relatively high. The flushing coefficient, calculated as the ratio of the volume of water leaving the lake to the volume of the lake exceeds 1.0 several periods of the year and for the entire year. Thus, certain amounts of nutrient delivered to the lake are washed through.

2. Spring is the most important time for nutrient load. It is estimated that spring rains and snow melt deliver most of the lake nu-

trients. For the lake during 1978-1979, 88 percent of the annual total nitrogen loading, 90 percent of the annual total phosphorus, and 66 percent of the annual suspended particulate matter occurred in the spring. The importance of spring loading was also demonstrated in varves (annual layers) identified in sediment cores. Recent portions of the cores were made up primarily of settled particles in the clay fraction of stream particulate matter, overlaid with organic particles of planktonic and littoral origin that accummulated in summer fall and winter.

3. The Indiana State Board of Health has suggested that flushing is a method which could be used for restoration of lakes such as Skinner Lake. Based on the time of year when nutrients occur, and the flushing coefficients of the lake, it can be suggested that flushing of Skinner Lake in late Spring (May) would result in improved water quality throughout the year. This would be expected to occur naturally in the event of extremely heavy rains in May.

Other Management Strategies

The model was also used to evaluate certain managment strategies which could have been applied to the lake. Since the Rimmell Drain accounts for nearly 80 percent of the water volume flowing to the lake, the effect of diverting this drain around the lake was considered.

Such an activity, the investigators reported, would have resulted in little improvement of the trophic state of the lake, since the reductions in nutrients would have been counterbalanced by a reduction in lake flushing.

Success of Treatments

Based on the spring interval of 1982, the settling basin was effective in reducing the sediment load of the Rimmell by 18 percent and the phosphorus load by 10 percent. This conclusion is based on an assumption that concentrations of both of these substances measured in water above the basin would be essentially that which would enter the lake if the basin was not present. Since the Rimmell provided 79 percent of the discharge to the lake during this interval, this amounts to a 14 percent reduction in sediment loading to Skinner Lake and an 8 percent reduction in phosphorus load to the lake.

It should be noted that the relationship between suspended material and phosphorus above and below the basin was not always consistent, however. Although particulate phosphorus was always reduced, Concentrations of total phosphorus in two-week composited samples from below the Rimmell settling basin were often slightly higher than or essentially the same as those from above the basin.

The success of the land treatment and sediment basin in improving the trophic status of Skinner Lake is illustrated in figure 7 of the Michigan State Report. This figure shows an improvement in the trophic state of the lake. Since the precipitation and discharge to the lake were very similar for 1979 and 1982, the improvement can be attributed to the land managment program.

Consideration of this figure also suggests that a greater improvement in the trophic state could have been achieved by doubling the size of the sediment basin. According to the MSU report, doubling the size of the sediment basin would have resulted in removal of nearly 100 percent of the suspended material from the stream.

Finally, removal of 100 percent of phosphorus from the water entering by way of the Rimmell Ditch would have moved the lake from the eutrophic to the mesotrophic category. This result could not have been achieved with a sediment basin, however. Such a result would require chemical treatment of the inflowing water.

Budget Summary

The following budget summary provides a summary of the sources of funding and the amounts spent during the Skinner Lake Project.

BUDGET SUMMARY

Item	EPA Funds	Local funds	Total
Salaries	80.005.71	35,978.50	115,084.21
Travel	3,437.67		3,437.67
Supplies	4,037.28	4,172.58	8,209.86
Work Plan	60.63		60.63
Final Report	3,364,67		3,364.67
Educational Pamphlets	738.12		738.12
SCS Contract	37,500.00	37,500.00	75,000.00
Monitoring	34,900.00		34,900.00
Land Treatment			
Maintenance	19,735.06		19,735.06
Large Basin	104,269.43	32,742.00	137,011.43
Rimmell Repair		32,154.27	32,154.27
Small Basin	6,816.90	6,816.90	13,633.80
Hardendorff	8,000	29,590.84	37,590.84
Tile/Rimmell	21,417.58	21,417.58	
Land Owners		61,108.79	61,108.79
Bauman Group	31,772.14	47,658.21	79,430.35
Minimum Tillage	4,329.78	8,245.02	12,574.80
Critical Area Vegetation	143.85	267.15	411.00
Diversions	627.25	1,165.00	1,792.25
Erosion Control Structures	2,754.45	4,131.67	6,886.12
Terraces	75,086.52	91,772.44	166,858.96
Tree Planting	218.86	328.89	547.15
Tile Mains	1,069.62	3,208.86	4,278.48
Vegetative Cover	5,556.91	8,335.37	13,892.28
Open Ditch	2,531.58	3,797.37	6,238.95
Animal Waste	3,756.57	8,765.53	12,522.10
Machinery	20,450.00	3,168.00	23,618.00
Higginbotham With County	7,400.00	9,042.00	16,442.00
TOTALS	458,563.00	450,446.37	909,029.37

PROJECT REPORT

A COOPERATIVE PROJECT TO DETERMINE THE EFFECTIVENESS OF LAND TREATMENT IN REDUCING THE TROPHIC STATE OF SKINNER LAKE, INDIANA

Department of Fisheries and Wildlife
Michigan State University
East Lansing, Michigan 48824

and

Noble County Soil and Water Conservation District
State Road #8, Rural Route #1
Albion, Indiana 46701

C.D. McNabb, B.J. Premo, J.R. Craig and M. Siami

July 1982

Introduction

This project was concerned with monitoring the runoff of an agricultural watershed to Skinner Lake in Noble County, Indiana. The watershed was treated extensively in 1978-79 under the US EPA Clean Lakes Program in cooperation with the US Soil Conservation Service to reverse the eutrophication of Skinner Lake. The goal of this project was to obtain data that could be used to evaluate the effectiveness of land treatment.

The project began after melt-water from the snowpack had discharged from the watersheds of the lake (24 March, 1982). The sampling period extended to 30 June, 1982. This has been shown as the primary rain-response period of the year for these watersheds (Gladon, et. al, 1981.) Our past sudies of 1979 and 1981 served as baseline data to describe characteristics of the waterhed and lake and as pre-treatment values to compare to 1982 data. Skinner Lake was determined to be phosphorus limited, therefore a phosphorus loading model was employed to compare pre- and post-treatment effects on the lake. Specifically, the objectives of this study were to:

(1) Evaluate the fit of Skinner Lake to a current lake phosphorus model (Vollenweider and Kerekes, 1980) in a pre-treatment setting.

(2) Utilize the Vollenweider and Kerekes (1980) model to predict which management strategies would most reduce the trophic state of Skinner Lake.

(3) Examine the effects of tile drainage on stream flow with flow duration analysis.

(4) Evaluate the success of the implemented land management practices in reducing the trophic state of Skinner Lake.

Methods

Daily discharge measurements (e.g. liters per second) were made on the Rimmell, Hardendorff, Croft-Sweet, Riddle, Weimer and Croft Drain (lake outlet) streams (Figure 1) during spring of 1979 (2/24 - 4/15), 1981 (3/9 - 4/20) and 1982 (3/24 - 6/30). During the rest of the 1978-79 and 1980-81 study years, flows were guaged at two week intervals. Discharge rates were determined using a "pygmy" Price-Gurley current meter. Stage height-discharge relationships were developed for the Rimmell stream and Croft Drain where automatic stage height recorders provided

Point discharge estimates were integrated over time to calculate total discharge volumes between measurements. It was assumed that the frequency of measurement was high relative to the rate of fluctuation in flow, and that a linear change occurred from one measured discharge value to the next. Volume of discharge during intervals was calculated by:

$$V = \frac{Q_o + 3Q_1}{8}(t_1 - t_o) + \frac{3Q_1 + Q_2}{8}(t_2 - t_1) \qquad (1)$$

where V = the volume of water discharged, and Q_o = the discharge rate measured at time 0 (t_o) (Glandon, et. al, 1981).

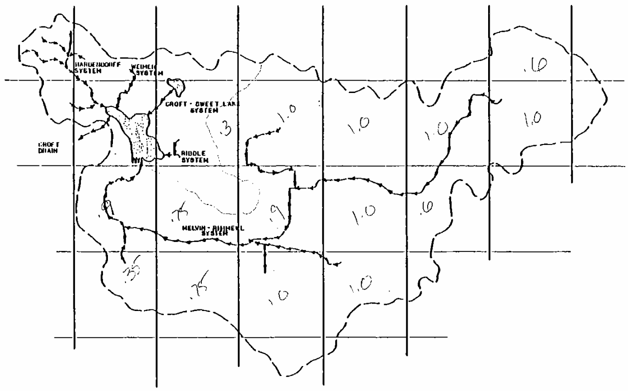


Figure 1 . The Skinner Lake watershed in Noble County, Indiana. Section lines form the grid shown. Sampling stations for measuring loading were located near the lake on each of the streams shown. Croft Drain is the outlet of Skinner Lake.

Yearly hydrographs, which represent a continuous plot of discharge over time, were constructed for all the streams. The hydrographs for the Rimmell stream and Croft Drain were constructed by converting the daily stage height recordings to discharge. Daily records of discharge were not available for other inlets during summer, fall and winter. Consequently an indirect method for hydrograph construction between the bi-weekly discharge measurements was developed from Barnes (1940). Basically, this method required calculating a stream's response time and recession rate from spring daily measurements and applying these to precipitation events that occurred during summer or fall.

A heated, recording precipitation guage installed at the Noble County Soil Conservation Service in Albion, Indiana provided a continuous record throughout the study period.

Flow duration analysis, as described by Chow (1964) was utilized to examine runoff variability between years in the Skinner Lake watershed. This method requires arranging the discharge values of a stream, over a season, or year, in order of their decreasing magnitude, then computing the percent of time each discharge is equalled or exceeded. A plot of discharges as ordinate vs corresponding percents of time as abscissas results in the flow duration curve. This duration curve represents a cumulative frequency curve of a continuous time series, displaying the relative duration of various magnitudes (Chow, 1964). These curves were constructed for the Rimmell, Riddle and Hardendorff streams on lognormal probability paper with discharge on the logarithmic scale and percent of time on the normal scale. The section of this curve between 50 percent of time and 15.87 percent of time appears as a straight line. The slope of this line is characteristic for a drainage basin and should remain constant from year to year in any one particular drainage area providing no charges in the drainage have occurred (Chow, 1964). The slopes of the Rimmell, Riddle and Hardendorff flow duration lines were examined for changes between years that could indicate effects due to tile drainage.

The volume of water in Skinner Lake was calculated from:

$$(2) \qquad V = \frac{h}{3}\left(A_1 + A_2 + (A_1A_2)^{\frac{1}{2}}\right)$$

where h is the vertical depth of a layer of water, A_1 is the area of the upper surface of that layer, and A_2 is the area of the lower surface of that layer (Wetzel, 1975). A bathymetric map of the lake (Figure 2) with bottom contours drawn at 2 m intervals was used to obtain areas for equation (2). Values of V obtained for each layer of 2 m thickness were summed to obtain the total volume of the lake.

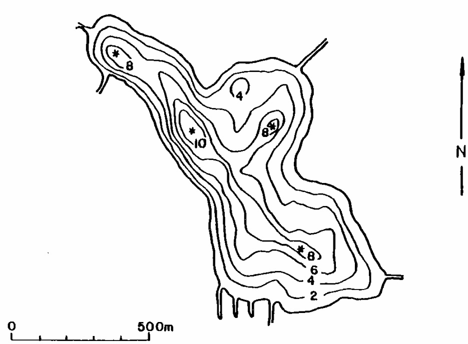


Figure 2. Bathymetry of Skinner Lake; contours shown in meters. Sampling stations for in-lake measurements are shown by stars.

The volume of water discharging into and from the lake was estimated for periods of snow melt (2/6 - 3/20/79; 1/20 - 3/9/81), spring rain (3/20 - 5/22/79; 3/9 - 6/5/81; 3/24 - 6/30/82), summer stratification (5/22 - 9/17/79; 6/5 - 10/15/81), fall and winter (9/6/78 - 2/6/79; 10/15/80 - 1/20/81) and for the entire year. Separation of the year into these periods was based upon whether major contribution to discharge was due to melting snow pack, spring rain events or base flow of inflow streams.

Separation of stream discharge due to snow melt from that due to rain events was accomplished by describing the expected hydrograph recession back to base flow had there been no spring rain (Glandon, et. al, 1981). The expected recession of each stream and the lake was characterized by those segments of the hydrographs undisturbed by rainfall (Barnes, 1940; Davis and Deweist, 1960). Spring rain intervals were determined as that period of time between snow melt and summer stratification when the streams were responding with peak discharges to rain events. During the summer stratification period, inflow streams were near base flow and Skinner Lake was stratified. Fall and winter intervals represented the remainder of the year. Discharge into and from the lake during all these intervals was determined by planimetry of the inflow stream and lake drain hydrographs.

The flushing coefficient of Skinner Lake was calculated as:

$$(3) \qquad \rho = V_o / V_t$$

where V_o is the volume out of the lake and V_t is the total volume of the lake. This value was calculated for intervals of the year and for the whole year. The flushing coefficient for just the epilimnion (to 4 m depth) during summer stratification was also calculated using epilimnion volume.

Stream water samples were collected daily during spring of 1979, 1981, and 1982. Aliquots from each stream's samples were composited for two weeks according to a discharge-proportional scheme (Flandon, et. al, 1981). Volume of aliquots was determined by considering that each sample (e.g. collected at time t_1) represented the volume of water discharged from the time halfway to the previous sample collection ($t_1 - t_0/2$) to halfway to the following sample collection ($t_2 - t_1/2$). Volume of discharge over the interval was calculated using equation (1). Composite samples were kept refrigerated and acidified (2 ml conc. H_2SO_4 l^{-1}) and were submitted to the laboratory biweekly for total nitrogen and total phosphorus analysis. During summer, fall and winter, stream grab samples were collected biweekly for nutrient analysis.

Lake volume proportional composite samples were collected from the upper and lower pelagial strata from four stations in Skinner Lake at two-week intervals throughout the ice-free season of 1979 and 1981. A depth-proportional compositing scheme was developed to combine aliquots from 3 depths within the upper pelagial water from all 4 sampling stations resulting in a single composited upper pelagial sample. Samples take at lower depth represented low volume of lake water so aliquots were smaller. The same method was used to produce a single composited lower pelagial sample. In 1982 water samples from the lake's outlet served as representatives of the lake's concentrations of nutrients and chlorophyll a.

The analytical methods utilized to process the samples from inflow streams and Skinner Lake were performed utilizing adaptations of procedures described in "Methods for Chemical Analysis of Water and Wastes" (EPA, 1971; 1979)

Total and total dissolved orthophosphate were measured by colorimetric determination of antimony-phospho-molybdate complex. Addition of ammonium molydate and antimony potassium tartrate to dilute solutions of phosphorus, in an acid medium react to form this complex. Ascorbic acid reduces the complex to a blue color which is proportional to the phosphorus concentration. Total phosphorus determination required persulfate oxidation followed by the above colorimetric determination

Nitrite-nitrate N was determined using the cadmium reduction method. Filtered samples were passed through a column containing granulated copper-cadmium to reduce nitrate to nitrite. The total amount of nitrite then present was determined by diazotizing with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine dihydrochloride to form a colored azo dye which was measured spectrophotometrically.

Ammonia nitrogen was determined using Nesslerization. Samples were buffered at a pH of 9.5 - 9.8 with a borate buffer in order to decrease hydrolysis of cyanates and organic nitrogen compounds. The sample was then distilled into a solution of boric acid. The ammonia in the distillate was determined spectrophotometrically by Nesslerization.

In order to analyze the amounts of total Kjeldahl nitrogen, the water sample was heated in the presence of concentrated sulfuric acid, K_2SO_4 and $HgSO_4$ and evaporated until SO_3 fumes were obtained and the solution became colorless. The cooled residue was then diluted, and made alkaline with addition of a hydroxide-thiosulfate solution. The ammonia was then distilled and determined after distilation by Nesslerization, specrophotometrically.

Residue analyses included determination of both dissolved and total forms. Total residue was measured by evaporating and drying 300 ml of well-mixed sample at 180 degrees C. After this, weight was determined and total residue recorded in mg/l. To determine organic residue, samples were then heated at 550 + 50 degrees C for one hour in a muffle furnace. The loss of weight on ignition was reported as mg/l folatile residue. Dissolved forms of residue were analyzed in water that was first filtered through a standard glass fiber filter, then processed as described above. A consistent relatioship between total residue concentration vs dissolved residue concentration was evident in all inlets. This relationship is described by figure 3. Since total residue is the most accurate analysis (due to filtering effects), concentration of suspended particulate residue was calculated by substracting dissolved residue as determined by figure 3 from analytically determined total residue.

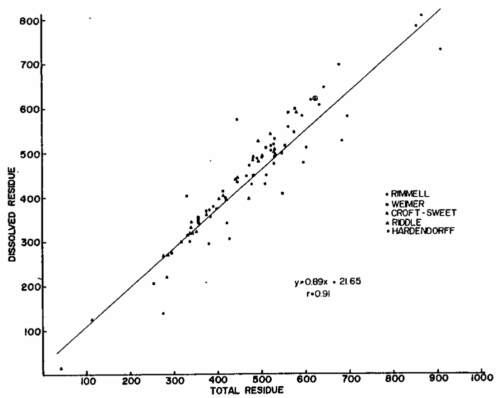


Figure 3. Relationship between total and dissolved residue in water of inlet streams to Skinner Lake, Indiana, 1979 and 1981.

Chlrophyll α in lake samples was determined as outlined in Strickland and Parsons (1965). Lake samples were processed immediately upon reaching the laboratory. Approximately 500 ml of water was filtered through Gelman Metricel Filters. Chlorophyll was extracted by grinding the filters in 90% aqueous acetone then centrifuged. Supernatant was then scanned with a spectrophotometer for absorbance from 800-400 nm. The sample was acidified with HCL and rescanned from 800-400 nm. Absorbance recorded at 665 nm before and after adicifying allowed for determination of chlorophyll α in mg/m^3.

Nutrient budgets for each inlet were calculated by multiplying concentration of the nutrient (analyzed from grab or composite sample) by the total discharge of the inlet over the sampling interval. Mean concentration of total nitrogen (TN) and total phosphorus (TP) in stream flow discharged to Skinner Lake were calculated by adding amounts (Kg) of TN or TP in discharge of five inflows to the lake and dividing by total volume of discharge over the interval in question.

In-lake phosphorus and nitrogen concentrations were calculated by using the following equation:

$$(4) \qquad [P_L] \doteq [(V_{epi})([P]_{epi}) + (V_{hypo})([P]_{hypo})] \div V_L$$

where V_{epi} = volume of the epilimnion at sampling time, $[P]_{epi}$ = phosphorus (or nitrogen) concentration determined from lake epilimnetic composite sample, V_{hypo} = volume of the hypolimnion at the sampling time, $[P]_{hypo}$ = phosphorus (or nitrogen) concentration determined from lake hypolimnetic composite sample, V_L = volume of Skinner Lake (2.157 x 10^6 m^3) and $[P]_L$ = in-lake phosphorus concentration. Whole lake ratios of total phosphorus to total nitrogen (TP/TN) were calculated using the values derived as described above. Mean in-lake concentrations were calculated by finding the average of the P and N values as calculated by equation (4) over the year or interval in question.

It was determined that Skinner Lake experienced internal hypolimnetic TP loading during summer stratification and it was of interest to calculate the effect of this TP internal loading on lake TP concentration during 1979. This was accomplished by considering the changes in lake storage of TP that occurred over the intervals 7/16 - 7/30, 7/16 - 8/21, 7/16 - 9/17 and 7/16 - 10/3. It was assumed that any internal TP loading that occurred during the first interval, 7/16 - 7/30, affected concentration throughout the summer stratification period. The hypolimnetic TP concentration on 7/16 was taken as the mean or base summer TP concentration and any subsequent hypolimnetic TP concentations which were greater than that of 7/16 were considered for internal loading. Kilograms of internal TP loading during any interval was taken as:

$$(5) \qquad TP_{load} = TP_{in} - TP_{out} - \Delta \text{ lake storage}$$

where TP_{load} = the kg of TP internally loaded to the lake during the interval, TP_{in} = the kg of TP entering in stream flow, TP_{out} = the kg of TP exiting the lake, and Δ lake storage = the difference in total kg TP the lake contains between the beginning and end of the interval. Total kg TP due to internal loading was then divided by the volume of the lake to get a concentration factor which represented lake TP concentration due to just internal TP loading. This concentration factor was calculated for each interval listed above. The measured in-lake TP concentration for 7/30, 8/13, 8/21, 9/17, and 10/3 were each corrected for internal loading by subtracting the concentration correction factor calculated for the intervals 7/16 - 7/30, 7/16 - 8/13, 7/16 - 8/21, 7/16 - 9/17 and 7/16 - 10/3 respectively. The resultant corrected TP concentration estimates were then averaged to obtain a corrected in-lake TP concentration for the summer stratification period. This value as well as the uncorrected in-lake TP concentration are considered in the results and discussion sections.

Results

Stream hydrographs developed for annual cycles in 1978-79 and 1980-81 indicate seasonal patterns of discharge divisible in periods of near base flow, runoff due to melt of the snow pack, discharge due to spring rains and summer runoff, and discharge of fall and winter. Total discharge associated with melt of the snowpack amounted to 53% and 21% of the annual stream discharge to the lake in 1978-79 and 1980-81 respectively. Stream discharge from rains during subsequent spring rain periods accounted for 35% of annual discharge in 1978-79 and 39% in 1980-81. In 1979, hydrographs for inflowing streams remained near base flow during summer stratification. Rain in June, 1981, resulted in runoff that made up a significant fraction (25%) of the total runoff for 1980-81. Base flows of fall and winter provided less than 10 percent of annual runoff to the lake in both complete years of measurement.

Spring rain flow duration analyses of the Rimmell, Hardendorff and Riddle inlets during 1979, 1981 and 1982 describe differences in the drainage patterns of the subwatersheds between these years. Both the Rimmell and the Riddle streams showed an increase in the slope of their respective flow duration lines from 1979 to 1981 and 1982. The increased slope of the lines in 1981 and 1982 indicate that these subwatersheds were drained faster promoting faster delivery of water to the stream in the later years. The slope of the Hardendorff flow duration lines remained the same between 1979, 1981, and 1982 indicating that drainage of this system was similar between years. The tiles of the Hardendorff system were laid prior to 1979. In the Rimmmell and Riddle systems, tiling was completed after spring of 1979.

Flushing coefficients (p) for Skinner Lake for various intervals of years studied are given in Table 1. Coefficients are broken down in Table 1 by season to emphasize an annual pattern that is probably typical of small-volume temperate zone lakes with relatively large watersheds. It can be noted that runoff from snow-melt tended to displace the volume of water in the basin during the period of ice-off from the lake. Subsequent runoff from rains freshened the lake spring overturns. Higher flushing coefficients in spring and summer in 1980-81 and 1982 resulted from high volume stream discharge following rain events of greater magnitude than observed in 1978-79. Completion of tile-drain systems between years of study may have contributed to this.

Spring runoff of total nitrogen (TN), total phosphorus (TP), and suspended particulate material (SPM) dominated the annual mass balance budgets measured for 1978-79 and 1980-81. Tables 2 and 3 compare the mean concentrations (mg/l/ha) and runoff coefficients (kg/ha) of TN,TP, and SPM for each of the subwatersheds during spring rain periods of 1979, 1981 and 1982. The highest values of these parameters were observed in 1981. This is likely the result of intense rain storms that occurred during spring which loosened and transported much soil material and associated nutrients. During spring of 1981 only 50% cover was present on the banks of the Rimmell and tile systems in the Rimmell watershed were still being laid. Loose excavated soil lay unprotected by ground cover and was eroded away during the spring storms. Concentrations of TN,TP, and SPM per hectare were generally lower during spring rain period of 1982 than in either 1981 or 1979. This could be a demonstration of success of the implemented management practices in reducing nutrient loading from the watershed.

Table 1. Flushing coefficients ($\rho = V_{out}/V_{lake}$) for Skinner Lake

Period	1978-79	1980-81	1982
Fall Overturn and Winter	0.02	0.21	----
Snow Melt	1.30	1.12	1.02
Spring Overturn	1.06	2.05	1.68
Summer Stratification	0.17	1.92	----
Whole Year	2.55	5.30	----

Table 2. Mean concentration of total nitrogen (TN), total phosphorus (TP), and suspended particulate material (SPM) in runoff from watersheds of Skinner Lake during spring rain periods.[1]

	TN (mg m^{-3} ha^{-1})			TP (mg m^{-3} ha^{-1})			SPM (mg m^{-3} ha^{-1})		
Watershed	1979	1981	1982	1979	1981	1982	1979	1981	1982
Rimmell[2]	2.8	1.8	1.5	0.05	0.18	0.07	8	23	12
Hardendorff	33.0	46.7	47.5	1.29	1.50	1.08	183	428	107
Riddle	52.5	48.3	23.9	1.48	2.34	1.33	168	710	149
Croft-Sweet	24.3	12.1	12.9	0.41	0.46	0.30	66	297	57
Weimer	132.8	75.7	29.4	1.41	3.64	1.46	452	1738	266

1. From March 20 to April 18, 1979; April 5 to June 5, 1981; April 5 to June 15, 1982.
2. Values indicate concentrations above the settling basin.

Table 3. Runoff coefficients for total nitrogen (TN), total phosphorus (TP), and suspended particulate material (SPM) for watersheds of Skinner Lake, during spring rain periods.[1]

	TN (kg ha^{-1})			TP (kg ha^{-1})			SPM (kg ha^{-1})		
Watershed	1979	1981	1982	1979	1981	1982	1979	1981	1982
Rimmell[2]	4.3	6.7	3.6	0.08	0.68	0.17	12	88	28
Hardendorff	4.8	12.1	7.8	0.19	0.39	0.18	26	111	18
Riddle	2.0	4.6	4.4	0.06	0.22	0.25	6	68	28
Croft-Sweet	2.1	2.8	3.3	0.04	0.11	0.08	6	68	15
Weimer	2.0	5.0	1.0	0.02	0.24	0.01	7	114	2

1. From March 20 to April 18, 1979; April 5 to June 5, 1981; April 5 to June 15, 1982.
2. Values indicate concentrations above the settling basin.

Table 4. Values of a mass loading to discharge relationship (Ω)[1] for stream flow into Skinner Lake, Indiana during springs of 1979, 1981 and 1982.

	1979 vs 1981[2]	1981 vs 1982[3]	1979 vs 1982[4]
TN	1.08	0.46	0.49
TP	1.38	0.50	0.64
SPM	3.98	0.40	1.46

1. $\Omega = M_y/M_{y-1} \div Q_y/Q_{y-1}$ where M = mass of nitrogen (TN), phosphorus (TP) or suspended particulate material (SPM) delivered to Skinner Lake by stream flow in spring of one year (y) compared to the previous year (y-1); Q = discharge in m^3/day.
2. $\Omega = M_{81}/M_{79} \div Q_{81}/Q_{79}$
3. $\Omega = M_{82}/M_{81} \div Q_{82}/Q_{81}$
4. $\Omega = M_{82}/M_{79} \div Q_{82}/Q_{79}$

Quantities of nutrients and SPM delivered to the lake during spring runoff from watersheds were compared between years using the following relationship:

$$\Omega = M_y / M_{y-1} \div Q_y / Q_{y-1} \qquad (6)$$

where M is mass of nitrogen, phosphorus, or SPM delivered to Skinner Lake by combined stream flow in the spring of one year (y) compared to a previous year (y-1), and Q is discharge (m^3 day^{-1}). For intervals of comparable length (100, 106, and 95 days), the combined discharge (Q) of five streams entering the lake was 43,208 m^3 day^{-1} in 1979;59,504 m^3 day^{-1} in 1981 amd 44,617 m^3 day $^{-1}$ in 1982. Noticw, for example,when comparing 1979 to 1981, that if mass loading increased between years by the same factor as Q increased than $\Omega = 1$. If mass loading between years increased by a factor less than the factor for increase in Q, $\Omega < 1$; if mass loading increased between years by a factor greater than the factor for increase in Q, $\Omega > 1$. Table 4 shows the results of this analysis. In 1981, compared to 1979, TN loading was increased by approximately the same factor as Q, whereas stream discharge carried proportionally greater load of TP and SPM to the lake. This can be explained by the same reasons as mentioned previously, namely intense rain storms caused unusually high erosion. In 1982, loading of TN and TP to the lake was proportionally lower than in both 1981 and 1979, even though the Q values of 1979 and 1982 were very similiar. These results may demonstrate the success of the land management practices in reducing nutrient and sediment loading to Skinner Lake.

Table 5. Mean concentrations (mg/l) of total nitrogen (TN), total phosphorus (TP), and suspended particulate material (SPM) in composited samples of water above and below the Rimmell settling basin, 1982.

	Above Basin			Below Basin		
Period	TN	TP	SPM	TN	TP	SPM
3/24 - 4/4	3.59	0.351	--	3.12	0.274	--
4/5 - 4/19	4.48	0.224	53	3.28	0.242	42
4/20 - 5/4	2.45	0.056	16	2.37	0.056	15
5/5 - 5/17	1.77	0.035	21	1.65	0.053	21
5/18 - 6/1	7.61	0.283	24	6.95	0.288	22
6/2 - 6/18	6.37	0.316	20	7.11	0.231	19
6/19 - 6/28	3.88	0.161	23	4.30	0.095	20

During spring of 1982, analyses were conducted to determine the effectiveness of the Rimmell settling basin in reducing nutrient and sediment loading contributed by the Rimmell inlet to Skinner Lake. The design of the basin is shown in Figure 4. At low discharge this basin was designed to direct the Rimmell via a southern border channel toward the southeast corner of the basin. There the channel opens into the basin. Then the water flows downslope toward the northeast corner of the basin and then toward the northwest corner where it leaves the basin in a channel to the lake. At high storm discharge, during snowmelt and spring floods, the channel on the south border overflows its levee, spills onto the basin, and moves toward the outlet.

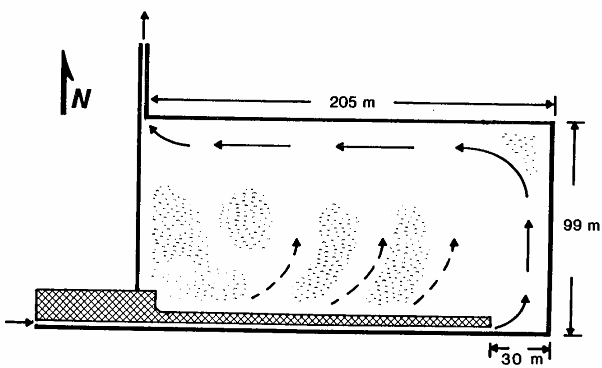


Figure 4. Design of the Rimmell settling basin (arrows represent direction of water flow).

Table 5 shows the concentrations of total nitrogen (TN), total phosphorus (TP) and suspended particulate material (SPM) measured in composited samples of water entering the basin (Above Basin) and water leaving the basin to the lake (Below Basin). During spring of 1982, the basin reduced suspended particulate load to Skinner Lake by 18% and reduced phosphorus load to the lake by 10%.

Concentrations of nitrogen and phosphorus in runoff from the watershed were expected to influence concentrations of TN and TP in the lake. Concentrations measured in the lake in 1979 are given in Table 6. Total nitrogen concentrations diminished from high values in the spring to low values in later summer and fall. The pattern of decrease in [TN] was much the same for mean concentrations calculated for the whole lake and for the epilimnion only. The range of concentrations observed for [TN] was 5.61 - 1.19 mg/l. Regarding [TP], a range of 0.021 - 0.137 mg/l was observed. High whole-lake mean [TP] in the interval 30 July - 3 October resulted primarily from high TP concentrations in the hypolimnion; they range from 0.154 - 0.221 mg/l during that time. An internal loading estimate calculated from equation (5) for 30 July - 3 October was 120 kg TP. Phosphorus was apparently released across the anarobic sediment surface that existed in the hypolimnion (Figure 5). It can be noted from Table 6 that concentrations of TP in the epilimnion from 30 July - 3 October were approximately 50% of whole-lake mean concentrations during that time. Whole-lake [TP] changed abruptly in October with initiation of fall overturn (Figure 5); mean concentration fell from 0.120 to 0.043 mg/l. Coincidence of overturn and decrease in [TP] suggest that phosphorus, particularly that in the hypolimnion, fell out to the sediments. Solving equation 5 for phosphorus mass balance in the lake basin for the period when fall overturn was initiated support this suggestion. Similar patterns of summer deoxygenation of the hypolimnion between periods of spring and fall overturn occurred in both years that oxygen was measured in this study. Summertime hypolimnetic internal phosphorus loading, discussed here for 1979, is likely a consistent feature of the annual phosphorus cycle of Skinner Lake.

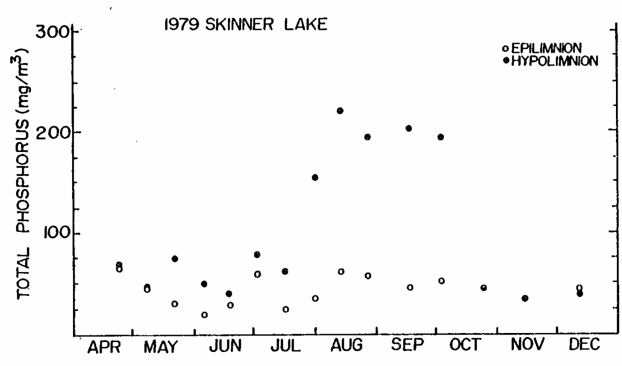


Figure 5. Total phosphorus concentrations (mg l^{-1}) in Skinner Lake during the ice-free period of 1979.

Total nitrogen:total phosphorus ratios for the epilimnion (trophogenic zone) of Skinner Lake are given in Table 6. They were found to range from 19 to 220. Sakamoto (1966), Chiaudoni and Vighi (1974), Allen and Kenny (1978), and Smith and Shapiro (1980 have been among those who considered the significance of this ratio in relation to nutrient limitation in lakes. Their work predicts that at TN/TP greater than 19, nitrogen limitation does not occur in Skinner Lake, and that algal yield in the trophogenic zone was likely phosphorus dependent. Algal yields as estimated from mean planktonic [chl a] in the epilimnion of Skinner Lake during summer thermal stratification in 1978 and 1979 were 17.29 and 15.15 mg m^{-3} respectively. Smith and Shapiro (1981) give an expected relationship between [chl a] and [TP] in trophogenic zones of phosphorus deficient lakes during summer stratification. Mean [TP] in the epilimnion of Skinner Lake in summers of 1978 and 1979 was 44 and 42 mg m^{-3}. Fit to the relationship of Smith and Shapiro (log [chl a] = 1.14 $\cdot$ log[TP] - 0.060) for these years was good; [chl a] at mean concentrations of phosphorus deviated between 8 and 13 percent from predicted concentrations.

Table 6. Concentrations of nitrogen and phosphorus (mg l^{-1}) in Skinner Lake during the ice-free period in 1979.

	Whole Lake			Epilimnion[1]		
Date	[TN]	[TP]	[TP][2]	[TN]	[TP]	[TN]/[TP]
April 23	5.61	0.068				83
May 7	4.50	0.047				96
May 21	4.54	0.055		4.65	0.031	150
June 5	3.57	0.036		4.61	0.021	220
June 18	3.42	0.037		2.92	0.027	108
July 2	2.95	0.067		2.94	0.060	49
July 16	2.75	0.042		2.90	0.024	121
July 30	3.28	0.081	0.045	3.50	0.034	103
Aug 30	1.94	0.137	0.053	1.19	0.062	19
Aug 21	1.91	0.106	0.058	1.48	0.059	25
Sept 17	2.69	0.121	0.059	1.69	0.048	35
Oct 3	1.82	0.120	0.047	1.20	0.052	23
Oct 24	1.28	0.043				30
Nov 14	1.38	0.036				32
Dec 12	3.07	0.044				70
Means	2.98	0.069		2.86	0.044	78

Fit of Skinner Lake data to the relationship between secchi disk transparency and [chl a] for ice-free seasons of 1978, 1979 and 1981 is shown with data for regional lakes in Figure 6. In spite of relatively high clay turbidity typically present and expected to cause non-biogenic shading, coordinates for Skinner Lake given in Figure 6 do not constitute outliers in the general trend of the data.

Vollenweider and Kerekes (1980) as a result of their work and that of others, gave an expected relationship between $[\overline{TP}]$ in inflow and $[\overline{TP}]$ in receiving lakes. Predicted in-lake concentrations of phosphorus are derived from:

$$[\overline{TP_L}] = \frac{[\overline{TP_i}]}{1 + t_w^{\frac{1}{2}}} \qquad (7)$$

where $[\overline{TP_L}]$ = mean in-lake TP concentration, $[\overline{TP_i}]$ = mean in-flow TP concentration and t_w = residence time of water in the lake basin, in years. The fit of 1979 Skinner Lake data to the model using inflow $[\overline{TP}]$ from streams is shown in Table 7. The effect of septic tank inflow, net seepage effects, and runoff from land immediately around the lake on $[TP_i]$ is unknown. Septic tank loading was estimated using a constant reported by Walker (1979) of 0.08 kg capita^{-1} year^{-1}. Since there are 125 cottages around Skinner Lake this amounts to 30 g TP/year and comprises only 2% of 1979 annual stream loading. Atmospheric bulk loading of TN and TP on the lake surface was measured during 1978-79. It amounted to 1.0 g TN m^{-2} and 0.02 g TP m^{-2}. While these measurements fell within the ranges predicted for the region by Uttormark et al. (1974), they consituted only 1.3% and 0.8% of the annual stream loading. Because of negligible influence on $[\overline{TP_i}]$, atmospheric and septic loading was not included in calculations of Table 7; $[\overline{TP_i}]$ is from stream loading.

Table 7. Fit of Skinner Lake data of 1978-79 to Vollenweider and Kereges (1980) estimates of in-lake TP calculated from:

$$[\overline{TP_L}] = \frac{[\overline{TP_i}]}{1 + t_w^{1/2}}$$

Period		Basis of Calculation	TP_i	t_w	Predicted TP_L	Actual TP_L
Whole Year 9/6/78 - 10/3/79		whole lake	231	0.39	142	82
Snow melt-spring overturn-summer strat. 2/6 - 10/3/79		whole lake	234	0.41	143	81
Spring overturn-summer strat.		whole lake	127	0.63	71	88
3/20 - 10/3/79	(1)	corrected* for internal loading by adding to $[TP_i]$	163*	0.63	91	88
	(2)	corrected* for internal load by subtracting from in-lake conc.	127	0.63	71	69*
	(3)	average of whole lake for spring and epilimnion for summer strat.	127	0.63	71	64*
Summer Strat.		whole lake	89	3.38	31	80
		corrected* for internal load by subtracting from in-lake conc.	89	3.38	31	50*

Discussion

As demonstrated previously, Skinner Lake is small relative to its watershed. This gives the lake extremely high yearly and seasonal flushing coeficients which allows the inflow water only very short residence time in the lake. When predicting in-lake [TP] that is influencing the mean growing season phytoplankton production, it is important to consider that in-lake [TP] to which the algae are exposed during the growing season. Because Skinner Lake is phosphorus limited we can utilize the Vollenweider and Kerekes (1980) model to make such predictions.

Vollenweider and Kerekes (1980) model predictions of $[\overline{TP_L}]$ for Skinnr Lake were made considering several different intervals of the year. Comparisons of predicted $[\overline{TP_L}]$ and actual $[\overline{TP_L}]$ for the year 1978-79 are shown in Table 7 which considers periods of entire year (9/6/78 - 10/3/79), snowmelt-spring overturn-summer stratification (2/6 - 10/3/79, spring overturn-summer stratification (3/30 -10/3/79), and summer stratification (5/22 - 10/3/79). Predicted $[\overline{TP_L}]$ that most clearly describe the observed growing season $[\overline{TP_L}]$ are those which were calculated by averaging $[TP_i]$ over the spring overturn-summer stratification period; this period includes that interval of time over which the lake was flushed once before stratification through to the end of summer. The periods which average $[\overline{TP_i}]$ over the whole year and during snowmelt-spring overturn-summer stratification both consider $[\overline{TP_i}]$ which has been flushed out of the lake before the growing season begins. Several snow-melt values of $[\overline{TP_i}]$ were very high, there these mean $[TP_i]$ predict higher values than observed in growing season $[TP_L]$. Consdiering only the period of summer sratification predicts lower $[\overline{TP_L}]$ than observed. This suggests that stream loading from spring overturn and summer most influence the growing season phosphorus concentration in the lake.

Vollenweider and Kerekes (1980) model assumes a completely mixed lake in which there is no internal loading of phosphorus to the water column from the sediments (Rast and Lee, 1978). An important event during summer stratification of Skinner Lake is internal P loading in the hypolimnion (Figure 5). This is a source of P unaccounted for in considering mean streamflow $[TP_i]$ during this interval. There are two ways to regard the effect of this internal P loading on in-lake [TP]: (1) the 120 kg of internal P loading can be incorporated in the $[\overline{TP_i}]$ and then used to predict $[\overline{TP_L}]$ over the period 3/20 - 10/3/79 or since (2) the internal TP loading increased hypolimnetic [TP] values it therefore caused a high calculated whole lake $[\overline{TP_L}]$ over the period. The whole lake $[\overline{TP_L}]$ observed concentrations can be corrected over the interval July 30 - Oct 3 so as to consider only the influence of inflow TP (see methods and Table 7). This gives a corrected lowered $[\overline{TP_L}]$ for the interval 3/20 - 10/3/79 (**in Table 7). Both of these methods of considering internal loading very closely predicted actual $[\overline{TP_L}]$ (Table 7). This suggests that internal loading is an important factor in calculating in-lake TP but does not suggest which $[\overline{TP_L}]$ is a more accurate description of the $[\overline{TP_L}]$ affecting phytoplankton productivity in the epilimnion.

It is reasonable to assume that during summer in a stratified, phosphorus limited lake, algae are responding to the [TP] of the epilimnion (Smith and Shapiro, 1981). During summer of 1979, the TN/TP ratios were > 19 in the epilimnion of Skinner Lake indicating phosphorus limitation (Allen and Kenny, 1978). The fact that internal P loading is a hypolimnetic event suggests that the corrected lower $[\overline{TP_L}]$ (69 mg/m^3) is a more realistic approximation of the effective $[\overline{TP_L}]$. Notice that this value is very close to the $[\overline{TP_L}]$ calculated by averaging whole lake [TP] values during spring overturn and only averaging epilimnetic [TP] during summer stratification (64 mg/m^3) (Table 7).

The Vollenweider and Kerekes (1980) model allows for the prediction of mean chlorophyll α concentration [chl α] by knowing $[\overline{TP_L}]$. i.e.:

$$\text{(8)} \qquad \log\,[\overline{\text{chl}\ \alpha}] = 0.99 \log\,[\overline{TP_L}] - 0.57$$

Both the corrected lowered $[\overline{TP_L}]$ and the $[\overline{TP_L}]$ calculated by considering only epilimnetic [TP] during summer stratification closely predict what the actual mean chlorophyll α level was in Skinner Lake in 1979. Actual chl α concentrations deviated between 15 and 8% from the predicted chl α calculated using the above two $[\overline{TP}]$ values.

Figure 7 is a graphical representation of the Vollenweider and Kerekes (1980) model. The figure demonstrates the predictable relationship between mean phosphorus concentration in the inlet and mean in-lake phosphorus concentration as well as chlorophyll α concentration. Data from the best fit 1979 data are shown on Figure 7. This diagram can be used to determine the reduction of Skinner Lake's influent phosphorus concentration necessary to improve its trophic condition. Use of Figure 7 and the knowledge of the important loading intervals of time to Skinner Lake allows for predictions of the effects of lowered inflow P concentration due to watershed management practices on lake phytoplankton productivity. For example, if in 1979 the Rimmell inlet had been diverted to drain into the lake's outflow, the effect on Skinner Lake could be hypothesized. Figure 7 shows that this would not lower the $[\overline{TP_i}]$ very much (114 mg/m^3) since the other inlets provide high [TP] to the lake also. Diverting the Rimmell would increase the residence time (t_w) to 2.35 since this stream presently provides a large percentage of inflow to Skinner Lake. The net effect of diverting the Rimmell in 1979 would be to reduce the $[\overline{TP_L}]$ to 45 and $[\overline{\text{chl}\ \alpha}]$ to 12 mg/m^3 according to the Vollenweider and Kerekes (1980) model. Another consideration involves the possible "best" effects that a settling basin could have in lowering $[\overline{TP_i}]$ in the Rimmell inlet. If in 1979, 100% of the [TP] was removed from the Rimmell inlet, the $[\overline{TP_i}]$ during 3/20 - 10/3/79 would have been 32 mg/m^3. Figure 7 shows that with residence time (t_w) equal to 0.63 year, the $[\overline{TP_i}]$ =32 mg/m^3 would place Skinner Lake into a mesotrophic category with $[\overline{TP_L}]$ = 18 mg/m^3 and [chl α] = 5 mg/m^3. Since the function of the settling basin is to remove suspended particulate material from the water, it is more realistic to consider the effect on Skinner Lake if the Rimmell settling basin were to remove 100% of the particulate phosphorus and 0% of the dissolved phosphorus from the water. In 1979, this possibility would put $[\overline{TP_i}]$ at 53 mg/m^3, and from Figure 7, $[\overline{TP_L}]$ = 20 mg/m^3 and $[\overline{chl\ a}]$ = 7.5 mg/m^3.

Results from 1982 indicate the effects of the land management practices in terms of both water and nutrient delivery to Skinner Lake. Spring rain flow duration analyses on the Rimmell system indicate that the extensive tile drain system laid in this subwatershed delivers water faster to the stream than before installation (1979). This same effect has been observed in studies of impact of urbanization. Leopold (1968) distinguished four interelated effects of urban storm drains including changes in peak flow, changes in total quantity of runoff, changes in water quality and changes in river channels. A number of others (Watkins, 1963; Kinoshita and Sonda, 1967; Nash, 1959) have shown that the urban hydrograph reaches a higher peak in a shorter time than the rural hydrograph; and that it also recedes more quickly.

Mean nutrient values during spring of 1981 from the Rimmell watershed suggest that this faster delivery of water may promote higher concentrations of TN, TP and SPM as a result of stream bank erosion. But this suggestion is contraindicated in 1982 when delivery of water occurred at the same rate as in 1981,yet TN,TP, and SPM concentrations were lower than the pretreatment values of 1979 (Table 4). This shows that the faster delivery of water promoted by the tile-drains does not counteract the success of the soil conserving land management practices in reducing nutrient load. Table 4 indicates that mean concentrations of TN were 49% of that in 1979 and mean concentrations of TP were 64% of 1979 even though discharges of the two years were very similar.

The Rimmell settling basin was effective in reducing a small percentage of nutrients and sediment from Rimmell water before it entered Skinner Lake. The basin's effective surface area was greatly reduced during low flows because the water flowed downslope in a channel approximately 46 m wide around the edge of the basin toward the outlet. The surface area over which water flows during low discharge is approximately 46 m wide around the edge of the basin toward the outlet. The surface area over which water flows during low discharge is approximately 11,845 m^2. The total surface area of the Rimmell settling basin is approximately 20,205 m^2.

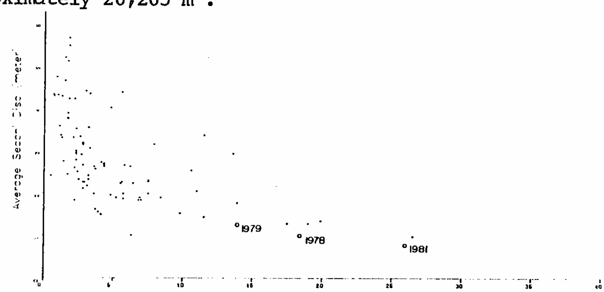


Figure 6. Coordinates for Skinner Lake data in three different years in relation to a line fit to mean summertime secchi disk transparency and mean summertime chl a concentration for 80 Michigan lakes in 1978 (from Michigan Department of Natural Resources, 1979).

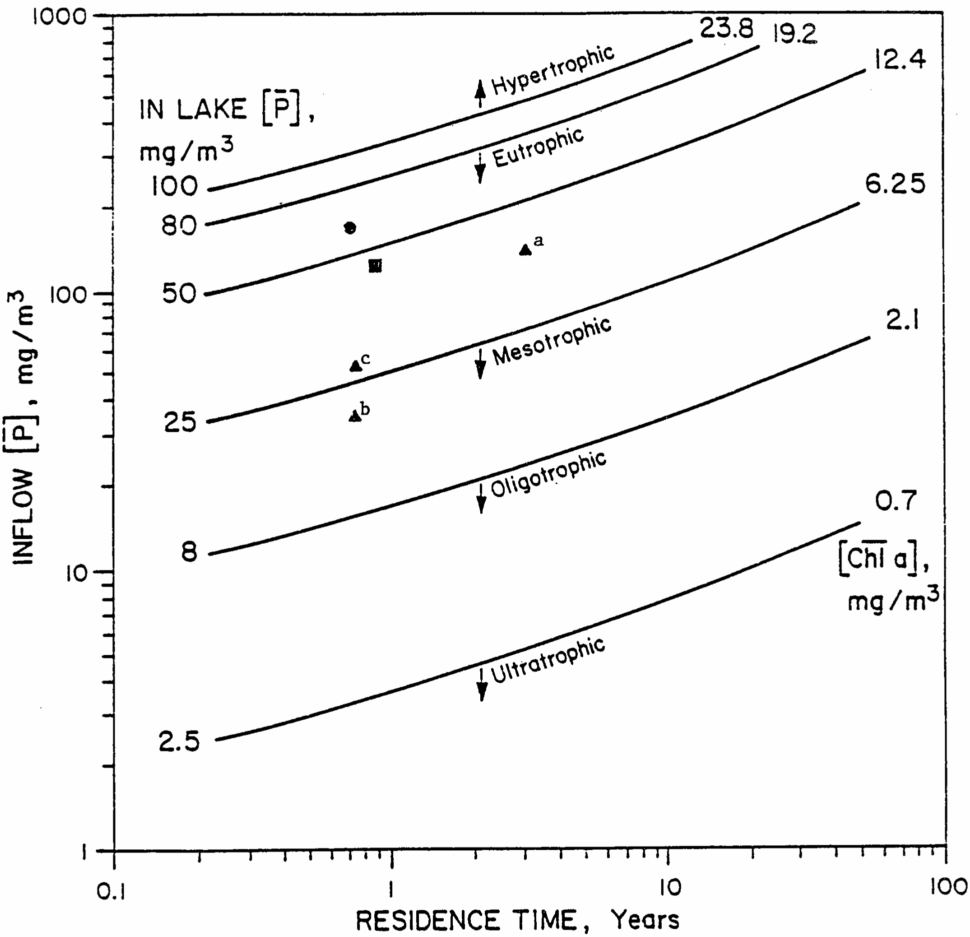


Figure 7. Position of Skinner Lake in the eutrophication model of Vollenweider and Kerekes (1980). ● shows coordinates for mean TP in 1979; ▲[a] probable case for Skinner Lake with diversion of Rimmell stream around lake to outlet stream; ▲[b] probable case for Skinner Lake if settling basin on Rimmell removed 100% TP in stream discharge; ▲[c] probable case for Skinner Lake if settling basin removed 100% TPP, 0%TDP; ■ shows coordinates for mean TP in 1982.

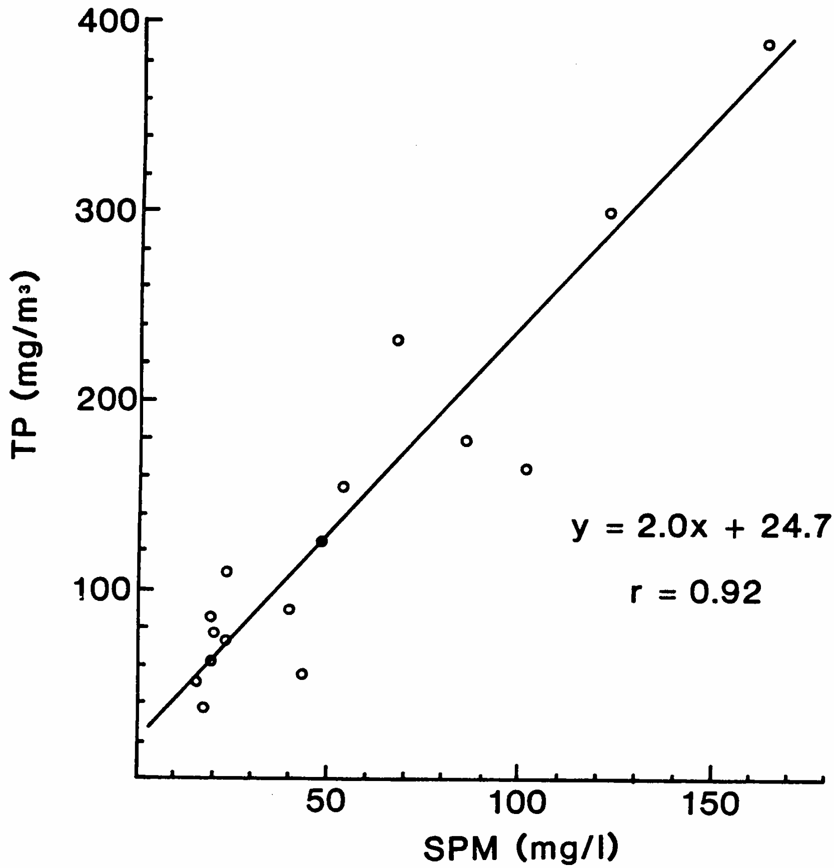


Figure 8. Relationship between total phosphorus (TP) and suspended particulate material (SPM) in the water of Rimmell stream, 1982.

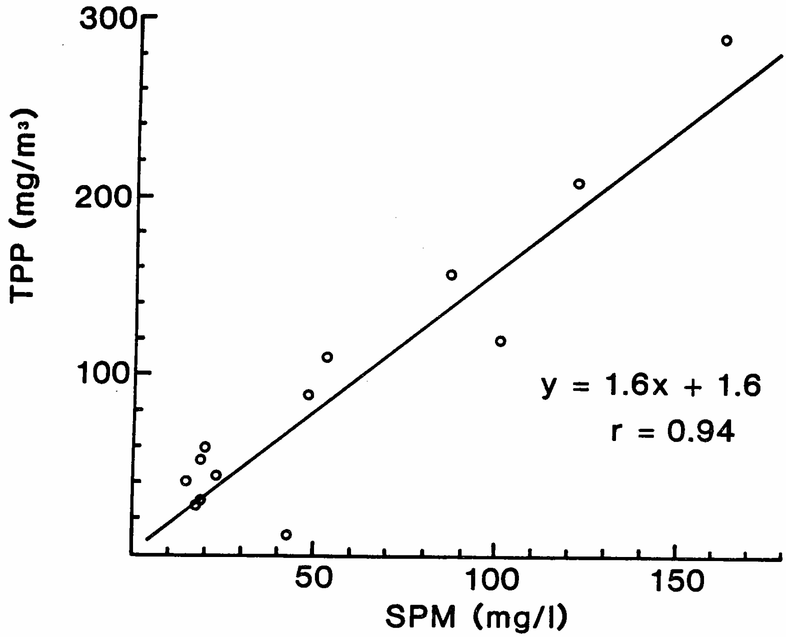


Figure 9. Relationship between total particulate phosphorus (TPP) and suspended particulate material (SPM) in the water of Rimmell stream, 1982. Total particulate phosphorus is calculated as difference between total and dissolved forms.

The theoretical size of a settling basin which would remove 100% of the suspended clay from the Rimmell water at base flow discharge is more than twice the size of the existing basin. This size can be calculated using the following derived equation and solving for the area:

$$[SPM]_{out} \cdot Q_{out} = [SPM]_{in} \cdot Q_{in} - A \cdot \psi \cdot \frac{[SPM]_{in} + [SPM]_{out}}{2} \tag{9}$$

Where $[SPM]_{out}$ = concentration of sediment in water going out of the basin, $[SPM]_{in}$ = concentration of sediment in water going into the basin, Q = discharge into and out of the basin, A = area of the basin and |psi| = settling rate of the suspended sediment. Equation 9 simply states that the amount of suspended sediment that leaves the basin should equal that which enters the basin minus any that settles within the basin. The term $([SPM]_{in} + [SPM]_{out})/2$ is taken as the mean concentration of SPM within the basin. Since clay is the dominant suspended sediment in this water (McCabe, 1980) and its particle radius is 0.2|mu|m, the settling rate (|psi|) is calculated to be 1.5×10^{-6} m/s using Stokes Law. Since the goal is 100% reduction of clay, this theoretical settling basin has $[SPM]_{out} = 0$. The average base flow discharge of the Rimmell is approximately 0.040 m^3/s. Using these values for solving for A in equation 9 gives a theoretical area of 53,333 m^2 needed to remove 100% of the suspended clay at base flow discharge. This is assuming that laminar flow conditions are maintained within the basin and that no other source of particulates (such as from the banks of the basin) is adding to [SPM]. Obviously a much bigger area would be needed to substantially reduce [SPM] during the high discharge intervals of snowmelt and spring rains.

Equation 9 can be used to calculate a predicted % reduction of [SPM] given the mean discharge and effective basin area over an interval since:

$$\frac{[SPM]_{out}}{[SPM]_{in}} = \frac{Q - \frac{A \cdot \psi}{2}}{Q - \frac{A \cdot \psi}{2}} = \frac{2Q - A \cdot \psi}{2Q - A \cdot \psi}$$

$$\%\ \text{reduction of}\ [SPM] = 1 - \frac{[SPM]_{out}}{[SPM]_{in}} \times 100 = 1 - \frac{2Q - A \cdot \psi}{2Q + A \cdot \psi} \times 100 \tag{10}$$

where A = effective area of the settling basin in m^2, |psi| = settling rate of clay = 1.5×10^{-6} m/s, and Q = average discharge into the basin over the interval (m^3/s.

Equation 10 can be used to predict the % reduction of [SPM] during intervals of 1982 (Table 8). These were compared to the actual % reduction of [SPM] in composited water samples taken above and below the settling basin over the intevals shown. Percent reduction in [SPM] calculated by using equation 10 very closely predicted the achieved reduction in [SPM] over the intervals studied. The effective surface area over which the water flowed was assumed to be the entire basin (20,295 m^2) when discharges were high (>0.80 m^2) and only the main channel area (11,485 m^2 when discharges were low <0.35 m^2/s). This assumption was substantiated by observation of water flow within the basin under different discharge conditions.

The effectiveness of the settling basin in reducing phosphorus and from the Rimmell water is not straightforward. Figure 8 demonstrates that there is a direct relationship between concentrations of total phosphorus and suspended particulate material in the Rimmell water. This relationship has a better fit if just total particulate phosphorus concentrations are compared to suspended particulate concentrations (Figure 9). This is reasonable since much of the phosphorus in natural water is sorbed onto solid phase material (Logan, 1981). McCabe (1980) also showed that suspended particulate residue levels were highly correlated with levels of particulate phosphorus and estimated the amount of phosphorus associated with suspended clay in the Rimmell to be approximately 1.39 mg P/g SPM. These facts should allow the assumption that with any reduction in amount of suspended particulate material in the water there should be a concomitant reduction in TP. But Table 5 demonstrates that this did not hold true for phosphorus in the Rimmell system in 1982. Concentrations of total phosphorus in 2 week composited samples from below the Rimmell settling basin were often slightly higher than or essentially the same as those from above the basin. Determination of total and dissolved phosphorus indicated that sometimes water flowing through the basin decreased its particulate phosphorus load but increased its dissolved phosphorus load.

Based upon the spring interval of 1982, the settling basin was effective in reducing the sediment load of the Rimmell by 18% and the phosphorus load by 10%. This is assuming that concentrations of both these substances measured in water above the basin would be essentially that which would enter the lake if the basin was not present. Since the Rimmell provided 79% of the discharge to the lake during this interval, this amounts to a 14% reduction in sediment loading to Skinner Lake, and an 8% reduction in phosphorus load to the lake.

Table 8. Predicted and actual percent reduction of suspended particulate material for Rimmell settling basin during 1982.

Period	Discharge (m^3/sec)	Effective Surface Area (m^2)	Predicted Percent Reduction	Actual Percent Reduction
3/24 - 4/4	0.88	20295	4	0[1]
4/5 - 4/19	0.89	20295	4	8
4/20 - 5/4	0.31	11845	6	6
5/5 - 5/17	0.15	11845	11	0[2]
5/18 - 6/1	0.21	11845	8	8
6/2 - 6/18	0.32	11845	6	5
6/19 - 6/28	0.12	11845	14	13

1. Indicates percent reduction based on instantaneous grab sample of 4/5.

2. Composite residue sample for below Rimmell basin was lost; grab sample for residue showed no difference in concentration above and below basin.

Conclusions

The resultant 1982 inflow [TP], in-lake [TP] and [chl |alpha|] observed in Skinner Lake are shown on Figure 7. Since the precipitation and discharge to the lake were very similar for 1979 and 1982, we can estimate that had land management not been practiced in 1982, values of [TP_i], [TP_L] and [chl |alpha|] would be similar to those of 1979. The graphical representation of the Vollenweider and Kerekes model represents the degree of success of the watershed management program in reducing the trophic level of Skinner Lake.

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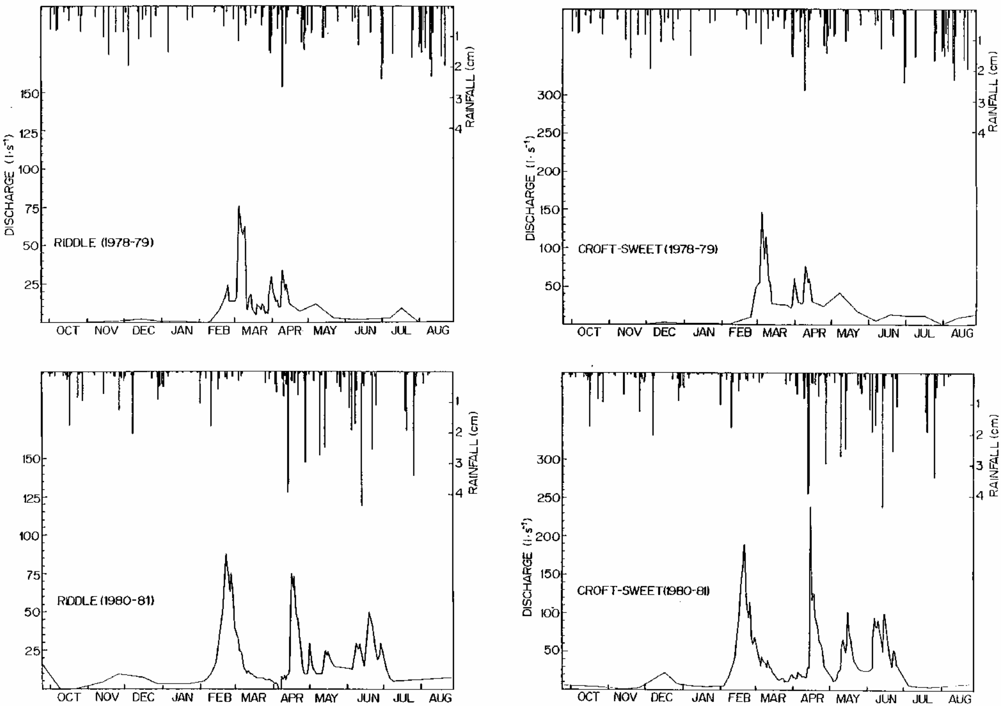
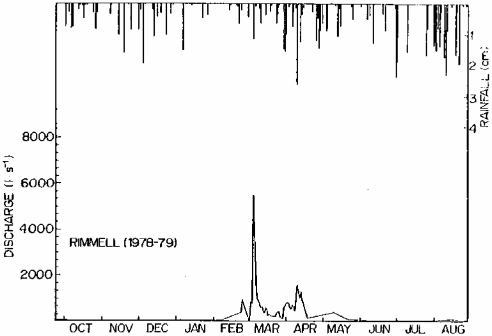
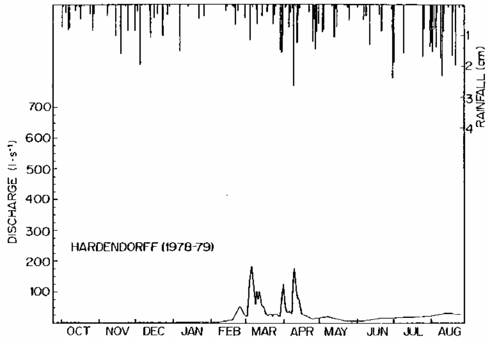
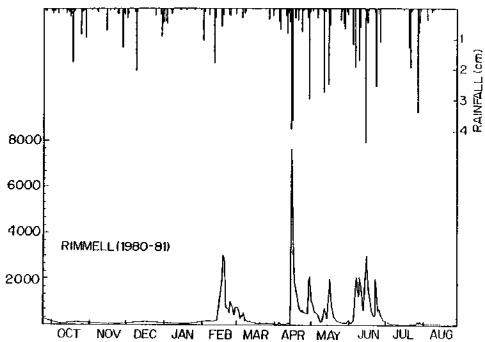
APPENDIX I

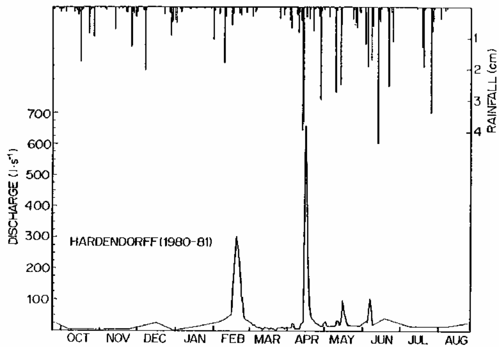
STREAM FLOW HYDROGRAPHS AND PRECIPITATION RECORDS FOR INLETS AND OUTLET OF SKINNER LAKE, INDIANA

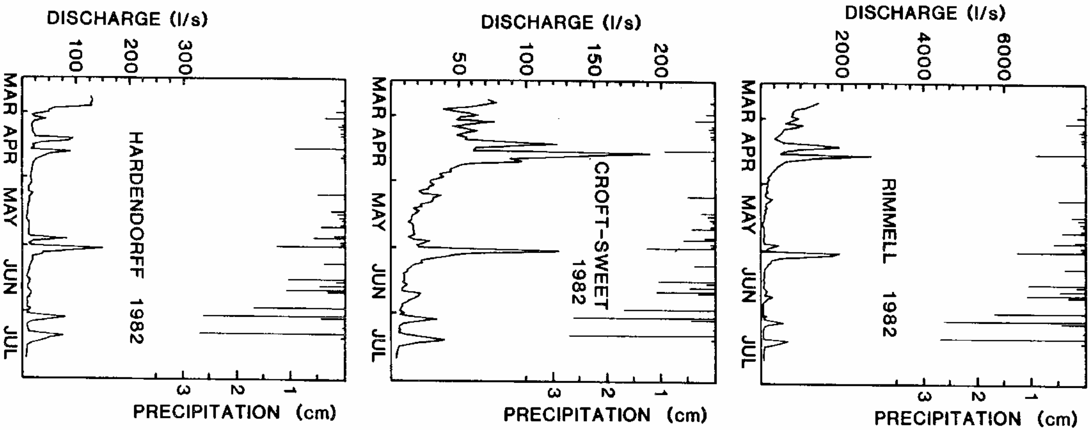

RIDDLE (1978-79)
CROFT-SWEET (1978-79)
RIDDLE (1980-81)
CROFT-SWEET(1980-81)
DISCHARGE ($l \cdot s^{-1}$)
RAINFALL (cm)
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG


RIMMELL (1978-79)
DISCHARGE (l·s⁻¹)
RAINFALL (cm)
8000
6000
4000
2000
1
2
3
4
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG

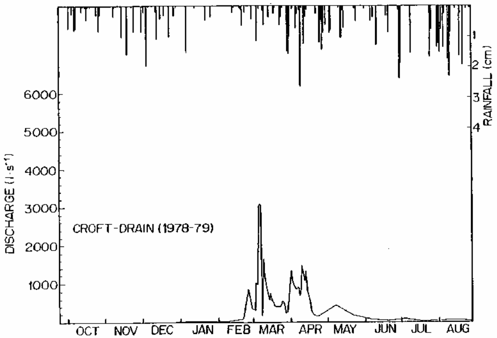

HARDENDORFF (1978-79)
DISCHARGE (l·s⁻¹)
RAINFALL (cm)
700
600
500
400
300
200
100
1
2
3
4
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG

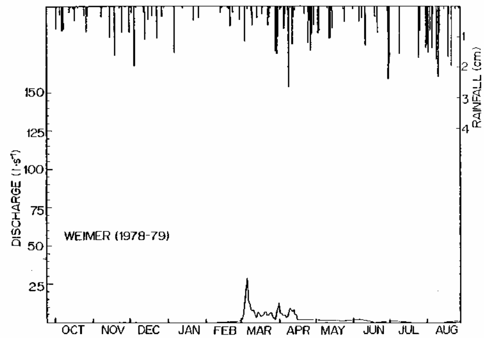

RIMMELL (1980-81)
RAINFALL (cm)
8000
6000
4000
2000
1
2
3
4
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG

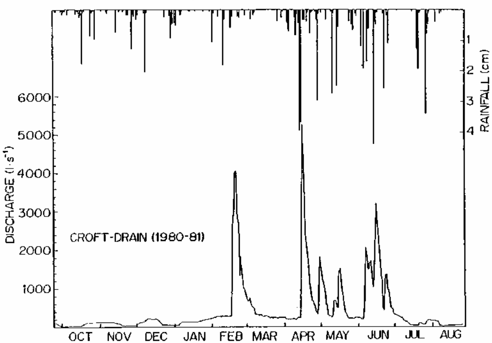

HARDENDORFF (1980-81)
DISCHARGE (l·s⁻¹)
RAINFALL (cm)
700
600
500
400
300
200
100
1
2
3
4
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG

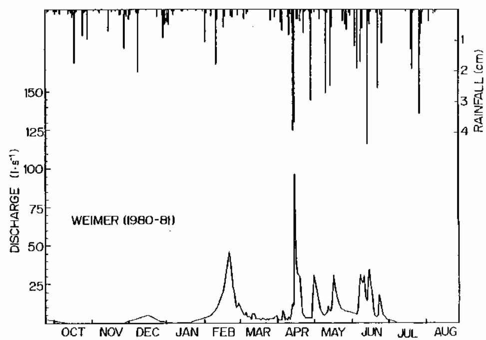


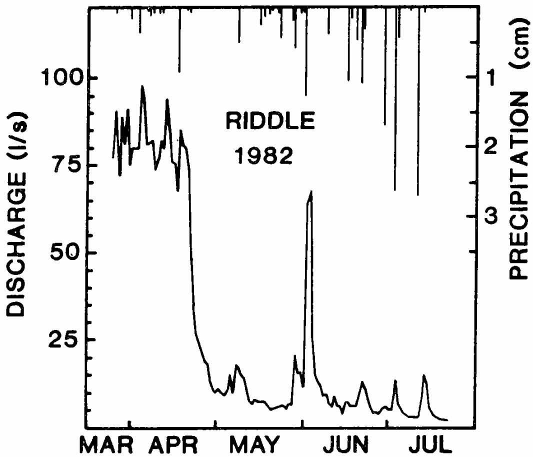
DISCHARGE (l/s)
100
200
300
MAR
APR
MAY
JUN
JUL
HARDENDORFF 1982
3
2
1
PRECIPITATION (cm)
DISCHARGE (l/s)
50
100
150
200
MAR
APR
MAY
JUN
JUL
CROFT-SWEET 1982
3
2
1
PRECIPITATION (cm)
DISCHARGE (l/s)
2000
4000
6000
MAR
APR
MAY
JUN
JUL
RIMMELL 1982
3
2
1
PRECIPITATION (cm)

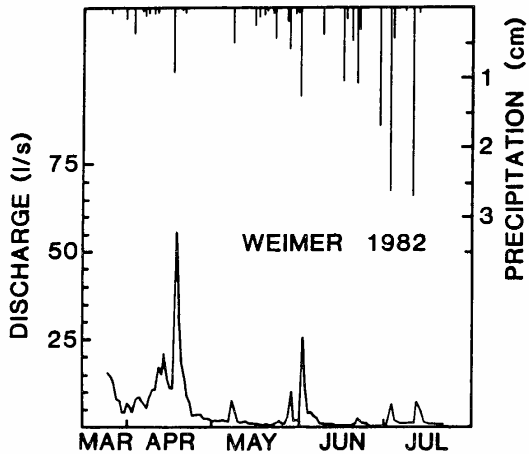

CROFT-DRAIN (1978-79)
DISCHARGE (l·s⁻¹)
RAINFALL (cm)
6000
5000
4000
3000
2000
1000
1
2
3
4
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG

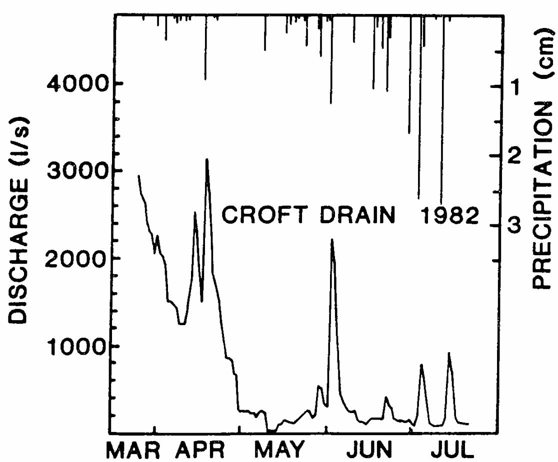

WEIMER (1978-79)
DISCHARGE (l·s⁻¹)
RAINFALL (cm)
150
125
100
75
50
25
1
2
3
4
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG


CROFT-DRAIN (1980-81)
DISCHARGE (l·s⁻¹)
RAINFALL (cm)
6000
5000
4000
3000
2000
1000
1
2
3
4
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG


WEIMER (1980-81)
DISCHARGE (l·s⁻¹)
RAINFALL (cm)
150
125
100
75
50
25
1
2
3
4
OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG

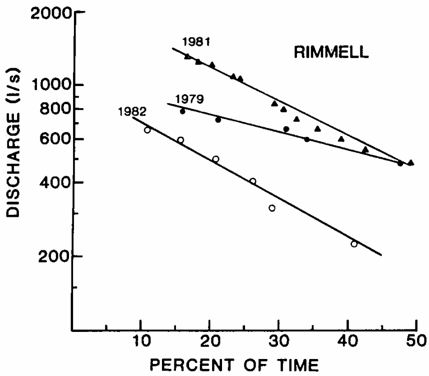

RIDDLE
1982
DISCHARGE (l/s)
PRECIPITATION (cm)
100
75
50
25
1
2
3
MAR APR MAY JUN JUL

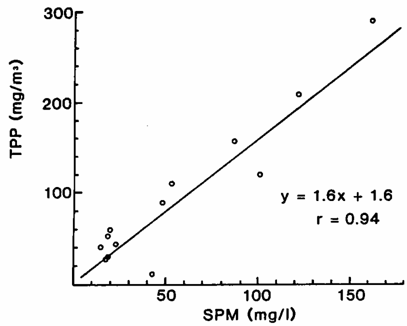

WEIMER 1982
DISCHARGE (l/s)
PRECIPITATION (cm)
75
50
25
1
2
3
MAR APR MAY JUN JUL

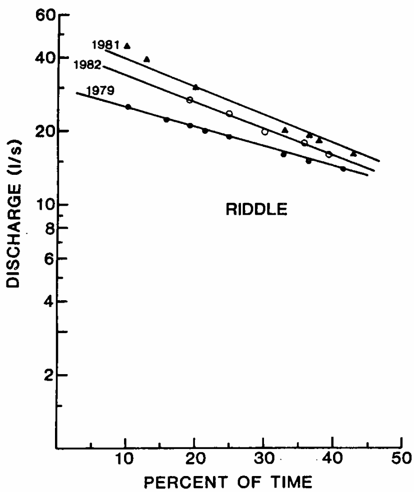

CROFT DRAIN 1982
DISCHARGE (l/s)
PRECIPITATION (cm)
4000
3000
2000
1000
1
2
3
MAR APR MAY JUN JUL

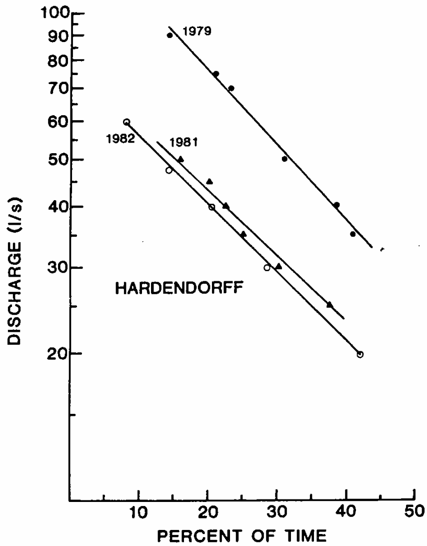
APPENDIX II

FLOW DURATION ANALYSIS OF RIMMELL, HARDENDORFF, AND RIDDLE STREAMS DURING SPRING OF 1979, 1981 AND 1982


RIMMELL
1981
1979
1982
DISCHARGE (l/s)
2000
1000
800
600
400
200
10
20
30
40
50
PERCENT OF TIME


TPP (mg/m³)
300
200
100
y = 1.6x + 1.6
r = 0.94
50
100
150
SPM (mg/l)


RIDDLE
1981
1982
1979
DISCHARGE (l/s)
60
40
20
10
8
6
4
2
10
20
30
40
50
PERCENT OF TIME


HARDENDORFF
1979
1982
1981
DISCHARGE (l/s)
100
90
80
70
60
50
40
30
20
10
20
30
40
50
PERCENT OF TIME